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DISINFECTION OF POULTRY PACKING PLANT EFFLUENTS
CONTAINING SALMONELLA. 1978.

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Disinfection of Poultry Packing Plant Effluents Containing Salmonella



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Report EPS 3-WP-78-9

Water Pollution Control Directorate
December 1978

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DISINFECTION OF POULTRY PACKING PLANT
EFFLUENTS CONTAINING SALMONELLA

by

Dearborn Environmental Consulting Services
Dearborn Chemical Company Ltd.

for the

Water Pollution Control Directorate
Environmental Protection Service
ENVIRONMENT CANADA

Report No. EPS 3-WP-78-9
December 1978

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ABSTRACT

This report is the result of an investigation to compare the relative effectiveness and economics of chlorination and ozonation for the control of salmonella in poultry processing effluents. The findings are based on laboratory and field studies conducted on the effluents from three poultry processing plants in Ontario. The surveys also were designed to assess the effect of plant design and operation on the incidence of salmonella in the final effluent.

The results indicated that none of the existing treatment systems eliminated the salmonella organisms. In one instance where the processor discharged to a municipal sewer system, salmonella were isolated in anaerobically digested sludge.

Chlorination and ozonation proved effective in controlling salmonella under both winter and summer operating conditions. Chlorination, however, was used successfully at a substantially lower concentration and marginally lower contact time. Chlorination increased the toxicity of the discharged effluent to fish, making dechlorination procedures necessary. Although these results were conclusive, the report indicates that disinfection requirements were site-specific.

The operating costs, including amortization of capital, for ozonation were estimated at \$0.17/1,000 lgal ($\$0.04/\text{m}^3$), compared to chlorination-dechlorination costs of \$0.054/1,000 lgal ($\$0.01/\text{m}^3$).

RÉSUMÉ

Le présent rapport résulte d'une enquête en laboratoire et sur le terrain visant à comparer l'efficacité relative et les coûts de la chloration et de l'ozonation des effluents de trois abattoirs ontariens de volaille, pour lutter contre la Salmonella. L'enquête visait, en outre, à évaluer les effets de la conception des établissements et de leur exploitation sur l'incidence de la Salmonella dans l'effluent final.

Les résultats démontrent qu'aucun des systèmes actuels de traitement n'élimine la Salmonella. Dans un cas où l'exploitant rejetait ses eaux usées dans les égouts municipaux, on en a isolé dans les boues digérées en conditions aérobies.

La chloration et l'ozonation se révèlent efficaces contre la Salmonella, tant en hiver qu'en été. Toutefois, la chloration agit à des concentrations beaucoup plus faibles et un peu plus rapidement que l'ozonation. Cependant, elle rend l'effluent plus toxique pour les poissons, rendant ainsi la déchloration nécessaire. Même si les résultats sont concluants, la nécessité de désinfecter l'effluent dépend directement de chaque établissement.

On a estimé les coûts d'exploitation, y compris l'amortissement, à 0,17 \$/1 000 gal (0,04 \$/m³) pour l'ozonation, comparativement à 0,054 \$/1 000 gal (0,01 \$/m³) pour la chloration suivie d'une déchloration.

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SUMMARY AND CONCLUSIONS

The human health hazard associated with the presence of salmonella in Canadian surface waters prompted the evaluation of control alternatives for one of the major known sources: effluents from poultry processing plants. The effectiveness and relative economics of ozonation and chlorination for control of salmonella in biologically-treated poultry processing effluents were evaluated under laboratory and pilot plant conditions. Surveys at three treatment facilities handling poultry processing wastewaters were designed to assess the effect of plant design and operation on the incidence of salmonella in the final effluent.

The presence of salmonella in treated effluents from three selected Ontario poultry processing plants was confirmed. Salmonella were evident throughout the treatment systems surveyed. None of the treatment processes investigated were effective in preventing the discharge of salmonella to receiving waters. At the municipal water pollution control plant, salmonella were isolated from samples of anaerobically digested sludge destined for land disposal. The agricultural use of digested sludges from waste treatment plants handling poultry processing effluents could result in the recycling of these pathogenic organisms in the environment. Further studies are recommended to define the extent of the problem and to determine the effect of design and operation of sludge handling facilities on the dissemination of pathogenic organisms, such as salmonella, through the natural environment.

The discharge of salmonella in poultry processing plant effluents can be successfully controlled by chlorination or ozonation. Pilot scale chlorination at an applied dosage of 10 mg/L available chlorine and 45 minutes contact time successfully controlled salmonella discharges under both winter and summer conditions at the plant where intensive studies were carried out. Ozonation, applied at 30 mg/L and 60 minutes contact time, was approximately 80 percent effective. However, disinfection requirements can vary significantly, depending on the effluent bacteriological and chemical quality.

Disinfection requirements are site-specific. Conditions which are found to be successful at a given site would not necessarily apply elsewhere. Specific conditions of plant operation and effluent quality must be evaluated at each site.

Chlorination substantially increased the toxicity of the secondary effluent to fish. Chemical dechlorination of the chlorinated effluent is required to minimize the impact of the discharge on the receiving stream. Ozonation did not significantly affect the toxicity of the secondary effluent.

The economics of ozonation do not compare favourably with those of chlorination-dechlorination. Operating costs, including amortization of capital, for ozonation were estimated at \$0.17/1,000 lgal (\$0.04/m³) as compared to chlorination-dechlorination costs of \$0.054/1,000 lgal (\$0.01/m³).

Conclusions

Based on the results of the investigative program, the following conclusions can be drawn:

- The presence of salmonella in discharges from wastewater treatment facilities handling process wastes from poultry processing plants was confirmed.
- Biological treatment, tertiary chemical treatment and effluent chlorination did not result in complete control of salmonella discharges under the operating conditions of the plants studied.
- The municipal treatment plant handling combined sanitary and industrial wastes showed evidence of salmonella in the final effluent and the raw sludges. Anaerobic digestion did not eliminate salmonella in the sludge removed for ultimate disposal on land. Further studies should be initiated to determine the extent of salmonella contamination of wastewater treatment plant sludges and to define the effects of the design and operation of digestion systems on the destruction of pathogenic organisms such as salmonella.

- Control of salmonella in secondary effluent from poultry processing plants is possible with either chlorine or ozone.
- Under laboratory conditions, chlorination was more effective for disinfection than ozonation. Salmonella were not isolated from the secondary effluent after treatment with 10 mg/L chlorine. Ozone, at dosages as high as 50 mg/L, did not provide equivalent disinfection.
- Under pilot plant conditions, chlorination at an applied dosage of 10 mg/L available chlorine and a contact time of 45 minutes was completely successful for control of salmonella under both summer and winter conditions at the poultry processing plant where intensive pilot plant studies were carried out.
- Ozonation at an applied dosage of 30 mg/L and a contact time of 60 minutes was successful approximately 80 percent of time in controlling salmonella under both summer and winter conditions at the same plant.
- Disinfection requirements can vary significantly at a given site. Under some circumstances, more severe chlorination and ozonation conditions than those selected as optimum did not control salmonella discharges in the secondary effluent.
- Disinfection requirements determined as optimum for a given site would not necessarily apply exactly elsewhere. Requirements are site-specific and conditions should be evaluated at each site.
- Chlorination of secondary effluent significantly increases the toxicity of the discharge. Chemical dechlorination can eliminate the increased toxicity associated with chlorination. Ozonation of secondary effluent did not significantly affect the toxicity.

- Capital costs for chlorination-dechlorination of poultry plant effluents at the conditions investigation are estimated to be \$43,000, based on flows of 1 lmgd (4,560 m³/d). Operating costs including amortization of capital are approximately \$0.054/1,000 lgal (\$0.01/m³).
- Comparable capital costs for ozonation of poultry plant effluents are estimated to be \$260,000. Operating costs are approximately \$0.17/1,000 lgal (\$0.04/m³).

1 INTRODUCTION

Localized outbreaks of human salmonellosis are experienced relatively frequently in Canada. It is estimated that the 5,000 incidents recorded annually represent only a small percentage of the total because weak cases are often not reported to medical authorities.

In most instances, human salmonellosis is attributed to the contamination of food products, despite the stringent controls applied within the food processing industry. A wide variety of possible sources of salmonella have been identified in the literature. Salmonella have been isolated in animal feedstuff, livestock, domestic and wild birds and eggs.

The presence of salmonella in treated effluents from meat and poultry processing plants has been established by several researchers (Tennant et al, 1975; Vanderpost and Bell, 1975). Salmonella contamination has been observed in Canadian surface waters. These findings indicate that a significant human health hazard is present due to the release of pathogenic organisms to receiving waters.

Little information is presently available on the effectiveness of various treatment techniques for control of salmonella discharges. Disinfection with chlorine is almost universally applied for control of bacteriological contamination. However, the adverse ecological effects associated with residual chlorine concentrations have been of concern to the regulatory authorities. Various procedures have been considered to alleviate the problem, including chemical dechlorination prior to discharge and the use of alternate disinfectants such as ozone.

It is apparent that very little work has been done with respect to the effectiveness of chlorine and ozone for salmonella disinfection, and the potential impact of the discharges on the aquatic environment. Dearborn Environmental Consulting Services was retained by Environment Canada to evaluate the relative merits of ozone and chlorine for treatment of poultry processing plant effluents.

The investigative program involved laboratory and pilot scale field evaluations of the two disinfection processes. Comprehensive sampling at three selected treatment facilities handling poultry processing wastes was included to assess the magnitude of the problem. This report presents the findings of the investigation.

2 STUDY OBJECTIVES

The primary objective of the study was to determine the relative merits of ozone and chlorine for control of salmonella discharges from poultry processing plants. The detailed objectives of the program were:

- to compare the relative efficiency of ozone and chlorine for disinfection of treated effluents from poultry processing plants.
- to define the optimum operating conditions for control of salmonella in poultry processing plant effluents by chlorination and ozonation.
- to determine the relative toxicity of poultry plant effluents after chlorination, chlorination-dechlorination, and ozonation.
- to review available operating data for three selected treatment facilities handling poultry processing plant wastes and assess the effectiveness for control of salmonella discharges.
- to assess the economic implication of chlorination, chlorination-dechlorination and ozonation for control of salmonella in treated effluents from poultry processing plants.

3 STUDY PROCEDURES

Three large Ontario poultry processing plants were selected for the study program. Wastewater treatment facilities at these plants, designated Plant 1, Plant 2 and Plant 3, covered a wide range of design. Plant 1 provides full secondary treatment of process wastes and chlorination prior to discharge. At Plant 2, tertiary chemical treatment using lime and alum follows the biological section of the system. Plant 3 discharges pretreated process effluents to the municipal sewer system. The combined industrial-sanitary wastes undergo secondary treatment at the municipal water pollution control plant.

The investigation consisted of three phases:

- Phase I - Laboratory Investigations
- Phase II - Evaluation of Performance of Selected Waste Treatment Plants
- Phase III - Pilot Scale Field Investigations

The procedures for each phase of the program are summarized in the following sections.

3.1 Phase I - Laboratory Investigations

Phase I of the program involved investigations of the range of conditions under which chlorine and ozone are effective for control of salmonella in the biologically-treated effluent from a major Ontario poultry packing plant.

Secondary effluent from Plant 1 was used for the laboratory investigations of chlorine and ozone efficiency. Previous sampling programs by Environment Canada had recorded the presence of salmonella in the treated effluent from this plant. The laboratory program required three separate samplings at this plant over a six-week period. The laboratory studies, and in particular the fish toxicity evaluations, required large volumes of effluent for each test. About 350 gallons (1.6 m^3) of effluent were collected on each occasion in plastic-lined 45-gallon drums. The samples were stored at approximately 5°C prior to the testing.

3.1.1 Description of chlorination equipment

During the laboratory evaluations, chlorination efficiency was assessed under batch conditions. Lined 45-gallon drums containing approximately 40 Imperial gallons (0.2 m^3) of secondary effluents and equipped with $1/4$ hp (0.2 kW) single-speed mixers were dosed with the desired quantity of 5% sodium hypochlorite solution. Samples were taken from the drum at desired intervals for analyses. For bacteriological testing, the chlorine residual was neutralized using sodium thiosulphate. For evaluation of the effect of dechlorination on the relative fish toxicity of the chlorinated effluent, a solution of sodium sulphite was added to an aliquot of the chlorinated sample to neutralize the chlorine residual.

3.1.2 Description of ozonation equipment

A laboratory scale continuous contact column was constructed for the ozone study. The laboratory apparatus is shown in Figure 1. The contact column consisted of a 12-foot (3.7 m), 4-inch (100 mm) I.D. plexiglass column equipped with two fine bubble diffusers. One diffuser supplied ozone to the bottom of the column; a second diffuser dosed ozone mid-way in the column. Rotameters were included to monitor the fraction of the gas flow supplied to each diffuser. Ozone was generated by a Labo-70 unit operating on dry compressed oxygen. Gas flow through the generator was maintained at 200 L/hr under all conditions to ensure that a constant degree of mixing was used in all tests. Ozone production was controlled by the power applied to the generator dielectric. Ozone output of the generator was calibrated using potassium iodide and sodium thiosulphate against the manufacturer's specifications. The secondary effluent was pumped at a constant rate of 2.2 L/min. to provide a liquid retention time of approximately 13 minutes in the column.

3.1.3 Laboratory study procedures

The initial laboratory test, screening test 1, involved a comprehensive evaluation of the effect of dosage and contact time on disinfectant efficiency. Chlorine was added to the poultry plant effluent at dosages of 5, 10, 25, and 50 mg/L. The disinfectant

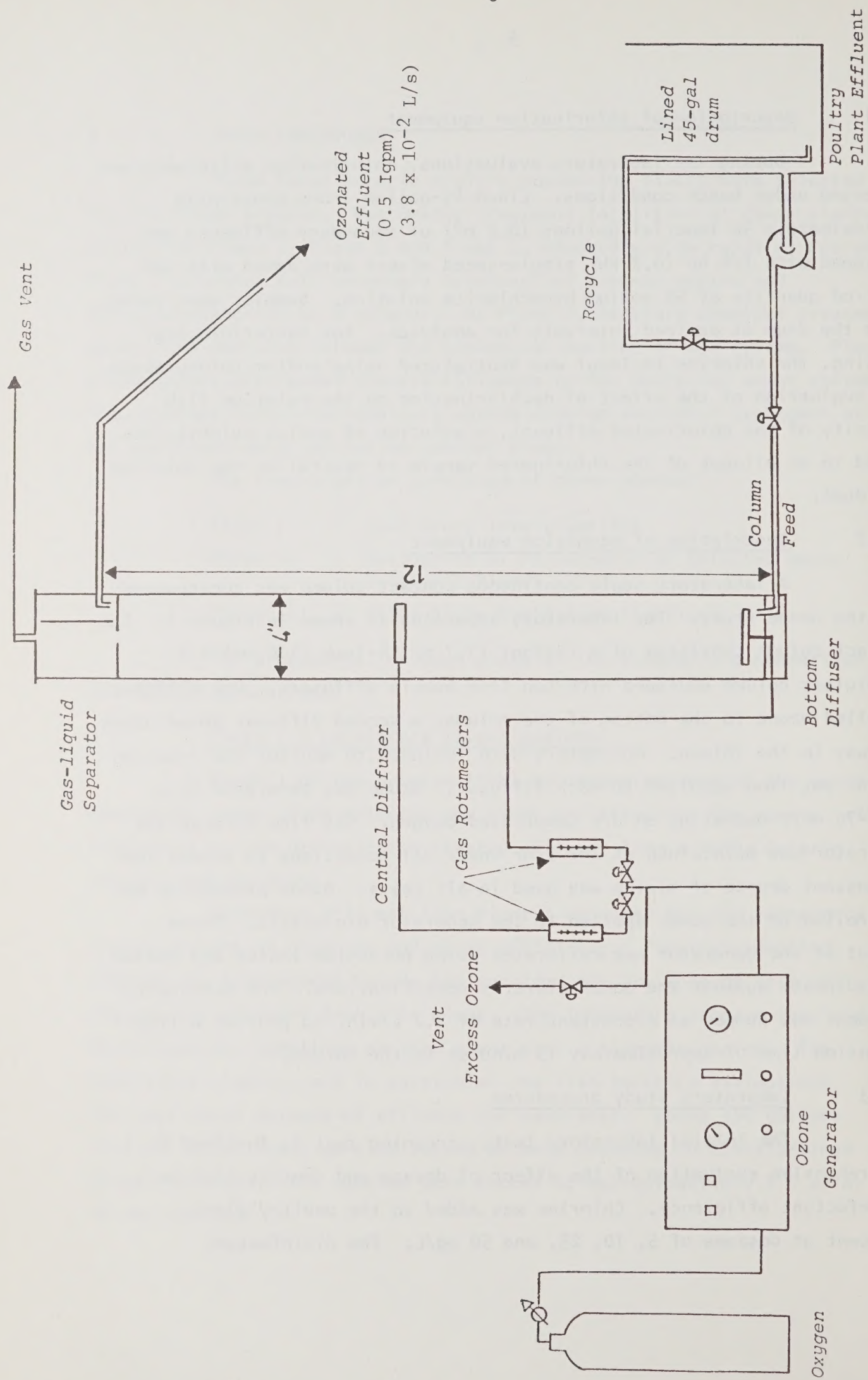


FIGURE 1. SCHEMATIC FLOWSHEET OF LABORATORY OZONATION SYSTEM

efficiency was determined by sampling each dosage after contact times of 15, 30, 45, 60 and 120 minutes and comparing the bacteriological characteristics with those of the untreated secondary effluent. Similarly, ozone was evaluated at dosages of 10, 20, 30, 40 and 50 mg/L to assess its disinfection effectiveness. The residual disinfectant concentration was determined analytically at each condition. Both free available and total residual chlorine were measured.

The ozone contact time is controlled by the time the relatively unstable ozone residual is present in the liquid. This duration can be extended by dosing ozone to more than one diffuser along the length of the contact column. During the initial screening test, only the bottom diffuser was used; however, during the second and third tests, the effect of adding 25 percent of the ozone to the middle diffuser was evaluated. The high dosage to the first diffuser is provided to satisfy the ozone demand of the waste; the secondary dosage to the middle diffuser provides the residual concentration for disinfection. The ozone system was operated for approximately 40 minutes, equivalent to three liquid retention times, to achieve stable conditions in the system prior to sampling.

In screening tests 2 and 3, the minimum chlorine dosages and contact times which successfully eliminated salmonella from the effluent in screening test 1 were evaluated. The lowest successful ozone dosages were assessed in screening test 2; however, the effect of dosing ozone at both diffusers was also investigated. During the second and third laboratory tests, the toxicity of chlorinated and ozonated samples was compared to that of the secondary effluent. The effect of dechlorination on the toxicity of the chlorinated samples was evaluated.

The chemical and standard bacteriological tests were conducted in accordance with the procedures outlined in the thirteenth edition of Standard Methods for the Examination of Water and Wastewater (1971). The incidence of salmonella was determined according to the test protocol suggested by Tennant et al (1975). The ATP (adenosine triphosphate) content of the samples was determined according to a Dearborn procedure.

An outline of the microbiological procedures is included in Appendix II, with particular emphasis on the salmonella isolation techniques.

Enumeration of salmonella concentrations in the waste streams was outside the scope of this study. Available enumeration procedures for salmonella are extremely time-consuming. From the test results, the presence or absence of salmonella in a 500 mL aliquot can be defined. A positive result could be obtained from the presence of a single viable salmonella bacterium in the aliquot due to the enrichment procedures. The same positive result would be recorded in the presence of extremely high salmonella concentrations. Thus, there are some anomalies in the results because the efficiency of disinfection, in terms of salmonella, was not quantified.

The toxicity of the disinfected and untreated secondary effluents was determined using 96-hour acute lethality static tests with Rainbow trout. The procedure is outlined in detail in Appendix III.

3.2 Phase II - Evaluation of Performance of Selected Waste Treatment Plants

Available operational and performance data from the three selected treatment plants were reviewed, with particular emphasis on the biological and disinfection processes. Basic design criteria of the three treatment facilities were evaluated.

Each of the selected waste treatment plants was monitored for a period of one week. Composite samples of the influent to the biological system, and secondary effluent were collected. Grab samples of aeration tank contents and chlorinated effluent were taken. In addition, at Plant 1, composite samples of the discharge from the polishing lagoon were obtained. At Plant 2, composite samples of the tertiary chemical treatment system effluent were collected. At Plant 3, the sampling program was concentrated at the municipal water pollution control plant. However, pretreated poultry plant effluent was sampled. Grab samples of the raw and digested sludge from the municipal facility were taken on three occasions. During the one-week monitoring period, as much data as possible were gathered regarding the operation of each individual treatment system.

3.3 Phase III - Pilot Scale Field Investigations

Phase III of the investigation provided on-site confirmation of the ozonation and chlorination results obtained under laboratory conditions in Phase I. Continuous pilot scale chlorination and ozonation systems were conducted under winter and summer conditions. Secondary effluents from Plant 1 and Plant 2 were used as feed to the pilot scale disinfection systems.

3.3.1 Description of chlorination pilot plant

The continuous chlorination pilot plant consisted of a plastic-lined 45-gallon drum equipped with a 1/4 hp (0.2 kW) single speed mixer. Overflow from the drum was set to provide a volume of approximately 40 lgal (0.2 m³) in the contact chamber. Secondary effluent feed rates of 2.7 lghpm (0.21 L/s) to 0.9 lghpm (0.07 L/s) provided retention times in the contact chamber of 15 minutes to 45 minutes. A dilute sodium hypochlorite solution was dosed continuously at the desired rate to the contact chamber by means of a chemical metering pump. Available chlorine concentration of the feed solution was determined prior to each run to ensure that the applied dosage was maintained as desired.

3.3.2 Description of ozonation pilot plant

For the on-site ozonation study, the Can 05b Pilot Plant, designed to operate with the Labo-70 ozone generator used during the laboratory studies, was used. The Labo-70 generator was described in Section 3.1.2. The Can 05b contact system consists of two columns in series, each equipped with a cone-type porous diffuser and a gas rotameter. Column 1 of the system is 18 feet in height and 4 inches in diameter, providing a total volume of 9.5 lgal. Column 2 is 18 feet in height and 6 inches in diameter, providing a total volume of 21.4 lgal. Gas-liquid flow in column 1 was countercurrent, ozone being applied at the bottom of the column and secondary effluent fed to the top. Ozonated effluent from column 1 entered the bottom of column 2 and was contacted co-currently with the remainder of the ozone-oxygen stream applied to the bottom of that column. The final effluent was collected from a gas-liquid separator at the top of column 2. As tested during the

laboratory studies, approximately 75 percent of the ozone dosage was applied to column 1; the remainder, controlled by the rotameters, was fed to column 2. Secondary effluent feed rates of 2.5 lpm (0.19 L/s) to 0.5 lpm (0.4 L/s) resulted in total column retention times of approximately 15 minutes to 60 minutes.

3.3.3 Pilot plant operating procedures

The parallel chlorination and ozonation pilot plants, as illustrated schematically in Figure 2, were operated from the same centrifugal feed pump supplying the treatment plant secondary clarifier overflow. Thus, identical feed was provided to both units. Both systems were operated for approximately three hours prior to sampling to ensure that stable conditions were attained in the units. Secondary effluent feed rates, chlorine application rate, and ozone generator conditions were checked on a regular basis to maintain good control of the systems.

After "steady-state" conditions had been attained in the pilot plants, sampling of the system effluents was commenced. Total and free available chlorine residual and ozone residual concentrations were determined immediately on-site. Bacteriological samples of treatment plant effluents and pilot plant effluents were obtained in sterile bottles containing sodium thiosulphate to neutralize the residual disinfectant. Bacteriological samples were returned to the laboratory for immediate analyses for ATP, fecal coliform, standard plate count and salmonella, according to the procedures outlined in Appendix II. Composite samples of screened process waste, secondary effluent and tertiary effluent were taken during the pilot plant runs for chemical analyses. The operating condition of the biological system was recorded in terms of aeration tank dissolved oxygen concentration, mixed liquor concentration, pH and sludge settleability.

The environmental impacts of ozone and chlorine were assessed by 96-hour fish bioassays on the pilot plant effluents. In addition, an aliquot of the chlorinated effluent was chemically dechlorinated by the addition of sodium sulphite prior to fish toxicity evaluation. Absence of chlorine residual was confirmed analytically after sulphite addition. Samples of secondary effluent and treatment plant final effluent were also taken for fish toxicity testing.

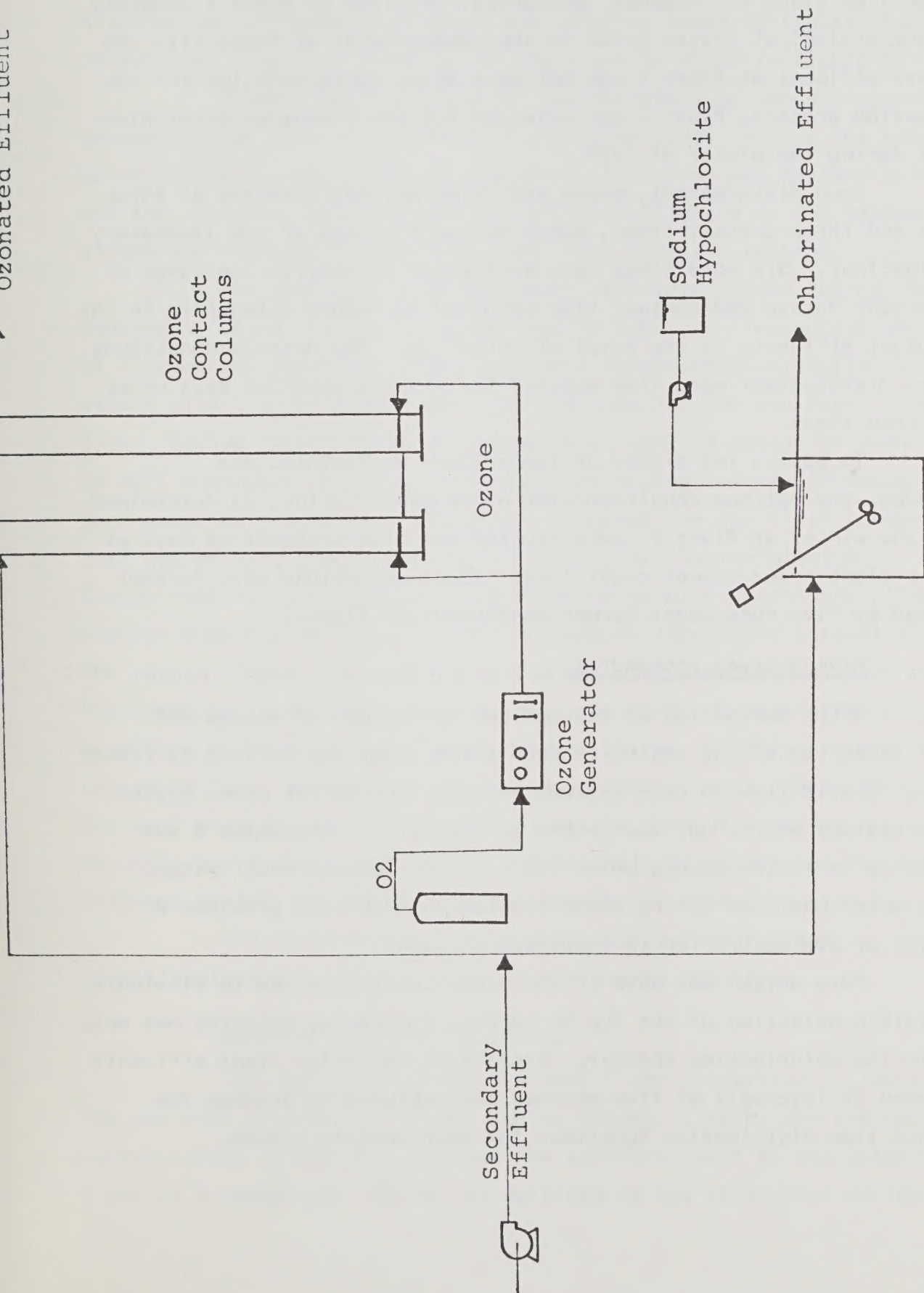


FIGURE 2. SCHEMATIC FLOWSHEET OF PILOT SCALE DISINFECTION SYSTEMS

Originally, optimization of the disinfection processes under winter conditions was proposed, based on the laboratory results obtained in Phase I at Plant 1. However, mechanical problems at Plant 1 severely upset the biological system prior to the commencement of Phase III. As secondary effluent at Plant 1 was not considered representative for the optimization process, Plant 2 was selected for the intensive pilot plant studies during the winter of 1977.

Each disinfectant, ozone and chlorine, was assessed at three dosages and three contact times, based on the findings of the laboratory investigations. Six conditions were duplicated to confirm the range of disinfectant dosage and contact time required to reduce salmonella in the pilot plant effluents to the level of detection. The optimum conditions for each disinfectant were then applied for five consecutive days under winter conditions.

To assess the effect of temperature on disinfectant efficiency, the optimum conditions for ozone and chlorine, as determined during the winter at Plant 2, were applied for five consecutive days at the same plant under summer conditions. These conditions were further evaluated by five runs under summer conditions at Plant 1.

3.3.4 Mixing study procedures

After definition of the optimum conditions of dosage and contact time, the mixing regime in each pilot plant was defined by tracer studies. Liquid flow in both systems and gas flow in the ozone system were maintained at the optimum levels of operation. Rhodamine B was injected as an instantaneous pulse input to the feed to each system. Process water was used during these studies to eliminate problems of turbidity or dye absorption in secondary effluent.

Pure oxygen was used in the ozone contact system to eliminate any possible oxidation of the dye by ozone. Similarly, chlorine was not added to the chlorination chamber. Samples of the pilot plant effluents were taken at intervals of five minutes and analyzed to produce the residence time distribution functions for each contact system.

4 RESULTS OF PHASE I - LABORATORY INVESTIGATIONS

Secondary effluent from Plant 1 was used to evaluate the disinfectant efficiency of ozone and chlorine under controlled laboratory conditions. The configuration of the plant is shown in Figure 3.

A detailed evaluation of the disinfection process operating parameters was done in the initial screening test. During the second and third screening tests, the disinfectant efficiency was further assessed and the relative impact of the disinfected effluents on the receiving stream was evaluated by 96-hour acute fish toxicity testing.

The quality of the secondary effluents tested during the laboratory scale studies is summarized in Table 1. To control the growth of filamentous bacteria, plant operators commenced chlorination of the return sludge several days prior to the sampling for the first screening test. Sodium hypochlorite was added at an applied dosage of about 12 mg/L available chlorine. Although the biological sludge exhibited poor settling properties, the sample obtained for the first screening test was of very good quality. In particular, bacteriological concentrations were extremely low compared to other secondary effluent samples obtained at Plant 1. For subsequent laboratory screening tests, the return sludge chlorination system was shut down several days prior to the scheduled sampling date to ensure that more representative samples of secondary effluent were obtained. Prior to the third laboratory screening test, mechanical problems developed with the 75-hp aerator in the west aeration basin. Therefore, at the time of sampling, only one aeration basin was operational. A noticeable deterioration in secondary effluent quality was evident in the sample for screening test 3.

The results of the laboratory scale disinfectant investigations are summarized in the following sections.

4.1 Laboratory Screening Test 1

The results of screening test 1 are summarized in Table 2. The addition of chlorine at the lowest dosage, 5 mg/L, and the shortest contact time, 15 minutes, reduced the coliform count to the detection limit of 2 counts per 100 mL, as outlined in the discussion of the

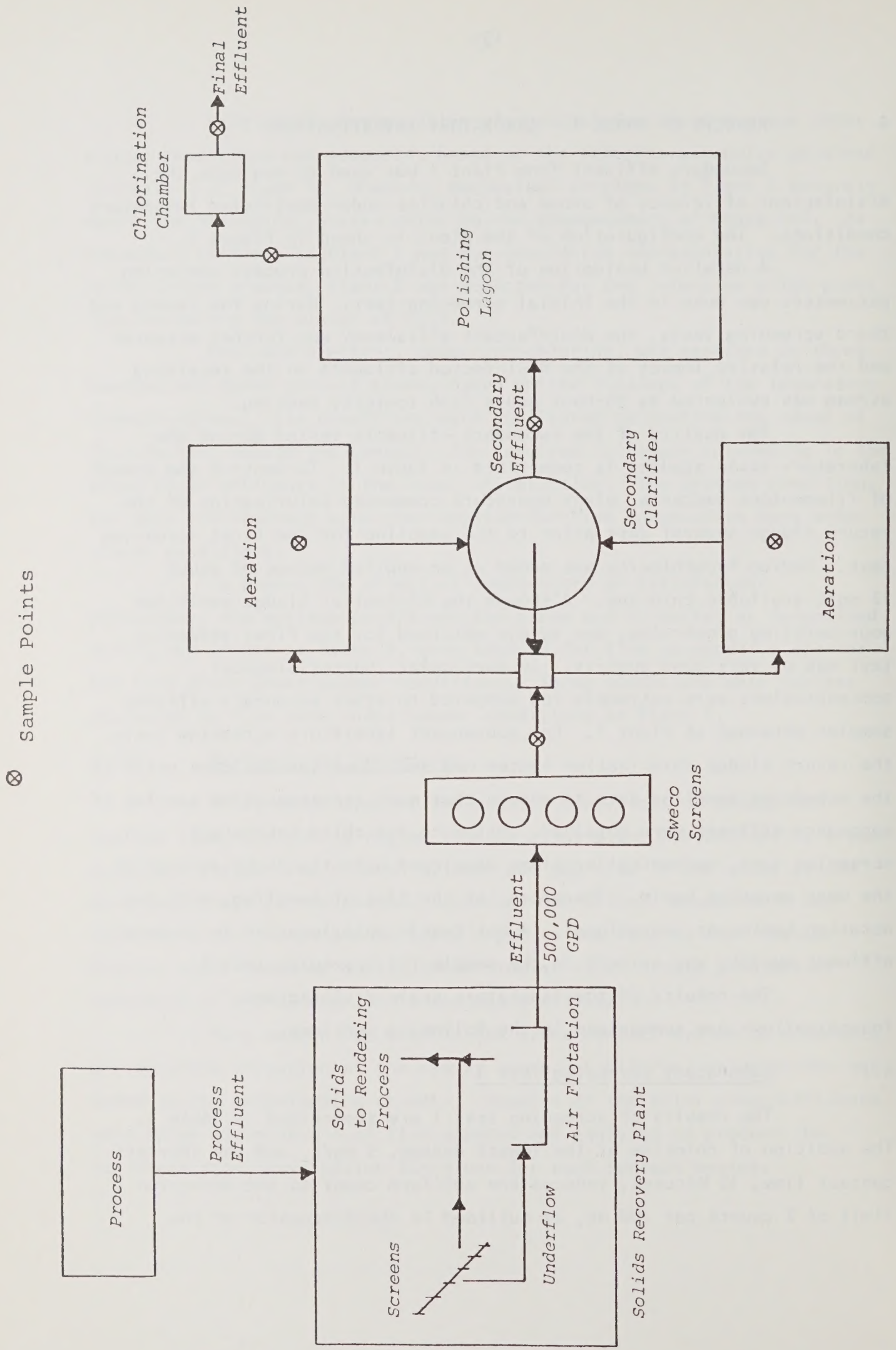


FIGURE 3. SCHEMATIC FLOWSHEET OF PLANT 1 WASTE TREATMENT SYSTEM

TABLE 1. LABORATORY DISINFECTANT SCREENING TESTS - QUALITY OF TESTED SECONDARY EFFLUENTS

Screening Test Number	Sampling Date	Chemical Quality				Bacteriological Quality			
		pH	BOD (mg/L)	Suspended Solids (mg/L)	Ammonia Nitrogen (mg/L)	Standard Plate Count (per mL)	Fecal Coliform Count (per 100 mL)	ATP Content (ng/mL)	Salmonella (presence/ absence)
1	28/10/76	8.0	<10	10	0.37	6,500	220	8.0	Present
2	30/11/76	7.6	38	43	2.64	430,000	78,000	44.0	Present
3	13/12/76	7.2	92	80	16.7	630,000	88,000	80.0	Present

TABLE 2. LABORATORY EVALUATION OF DISINFECTANT EFFICIENCY SCREENING TEST 1 - OCTOBER 29, 1976

Disinfectant	Applied Dosage (mg/L)	Contact Time (min)	Chemical Characteristics			Bacteriological Characteristics				
			pH	BOD (mg/L)	Disinfectant Residual (mg/L)		Standard Plate Count (per mL)	Fecal Coliform Count (per 100 mL)	ATP Content (ng/mL)	Salmonella (presence/absence)
					Total	Free				
Control	-	-	8.0	<10	-	-	6,500	220	8.0	Present
Chlorine	5	15	-	-	1.4	<0.1	18	<2	1.4	Absent
		30	-	-	1.0	<0.1	9	<2	0.48	Absent
		45	-	-	1.0	<0.1	6	<2	0.32	Absent
		60	-	-	0.9	<0.1	6	<2	0.20	Absent
		120	8.4	<10	0.8	<0.1	8	<2	0.23	Absent
	10	15	-	-	1.4	<0.1	17	<2	0.90	Absent
		30	-	-	0.8	<0.1	39	<2	0.35	Absent
		45	-	-	0.6	<0.1	18	4	0.25	Absent
		60	-	-	0.6	<0.1	10	<2	0.16	Absent
		120	8.4	<10	0.6	<0.1	8	<2	0.09	Absent
	25	15	-	-	15.0	5.2	10	<2	0.11	Absent
		30	-	-	14.0	5.2	<1	<2	0.06	Absent
		45	-	-	12.0	5.0	<1	<2	0.03	Absent
		60	-	-	12.0	4.8	<1	<2	0.04	Absent
		120	8.3	<10	12.0	4.8	<1	<2	0.01	Absent

TABLE 2. LABORATORY EVALUATION OF DISINFECTANT EFFICIENCY SCREENING TEST 1 - OCTOBER 29, 1976 (CONT'D)

			Chemical Characteristics			Bacteriological Characteristics				
			pH	BOD (mg/L)	Disinfectant Residual (mg/L)		Standard Plate Count (per mL)	Fecal Coliform Count (per 100 mL)	ATP Content (ng/mL)	Salmonella (presence/absence)
Applied Dosage (mg/L)	Contact Time (min)	Total			Free					
Chlorine	50	15	-	-	42.0	16.5	<1	<2	0.08	Absent
		30	-	-	41.0	16.5	<1	<2	0.09	Absent
		45	-	-	38.0	14.5	<1	<2	0.04	Absent
		60	-	-	36.0	16.0	<1	<2	0.02	Absent
		120	8.4	<10	36.5	14.5	<1	<2	0.03	Absent
Ozone	10	13*	7.8	<10	<0.01	-	850	18	1.45	Present
	20	13*	7.7	<10	0.09	-	265	16	0.37	Absent
	30	13*	7.7	<10	0.10	-	103	8	0.25	Absent
	40	13*	7.7	<10	0.19	-	213	6	0.21	Absent
	50	13*	7.7	<10	0.61	-	110	2	0.17	Absent

*0zone applied by means of bottom diffuser only.

Microbiological Methods in Appendix I. The standard plate count was reduced by more than 99 percent by the least severe chlorination conditions. All conditions more severe than 25 mg/L applied available chlorine and 30 minutes contact time reduced the standard plate count to the limit of detection, 1 count per mL (Appendix II).

Although the total bacterial concentrations in the secondary effluent were relatively low, salmonella were detected. However, salmonella were not isolated from samples of this effluent after any of the chlorination treatments.

As the least severe treatment reduced the fecal coliform concentration to the limit of detection, and most treatments reduced the standard plate count to the limit of detection, one cannot correlate dosage with disinfectant efficiency for this particular test. However, the ATP content, which was not reduced to the detection limit of the assay, provided a reasonable correlation to the disinfecting conditions.

In Figure 4, the effect of dosages and contact time on the ATP content is illustrated. The results indicate the trend towards reduced bacterial viability, as measured by the ATP content, with increasingly severe chlorination conditions.

Disinfection with ozone produced much less dramatic reductions in bacteriological concentrations. At applied dosages as high as 50 mg/L ozone, the fecal coliform and standard plate counts were above the limits of detection. Good correlation between ozone dosage and disinfectant efficiency was evident in fecal coliform concentrations. Standard plate counts after treatment showed a wider degree of variation.

A dosage of 10 mg/L ozone was not adequate to eliminate salmonella from the secondary effluent. At dosages of 20 mg/L and higher, salmonella were not detected in the disinfectant effluent.

A relationship between ozone dosage and ATP content is evident, as shown in Figure 5. However, there is no significant direct correlation between ATP content and either the standard plate count or the fecal coliform count. Not all microorganisms are detected in standard plate counts and fecal coliform counts. In addition, a

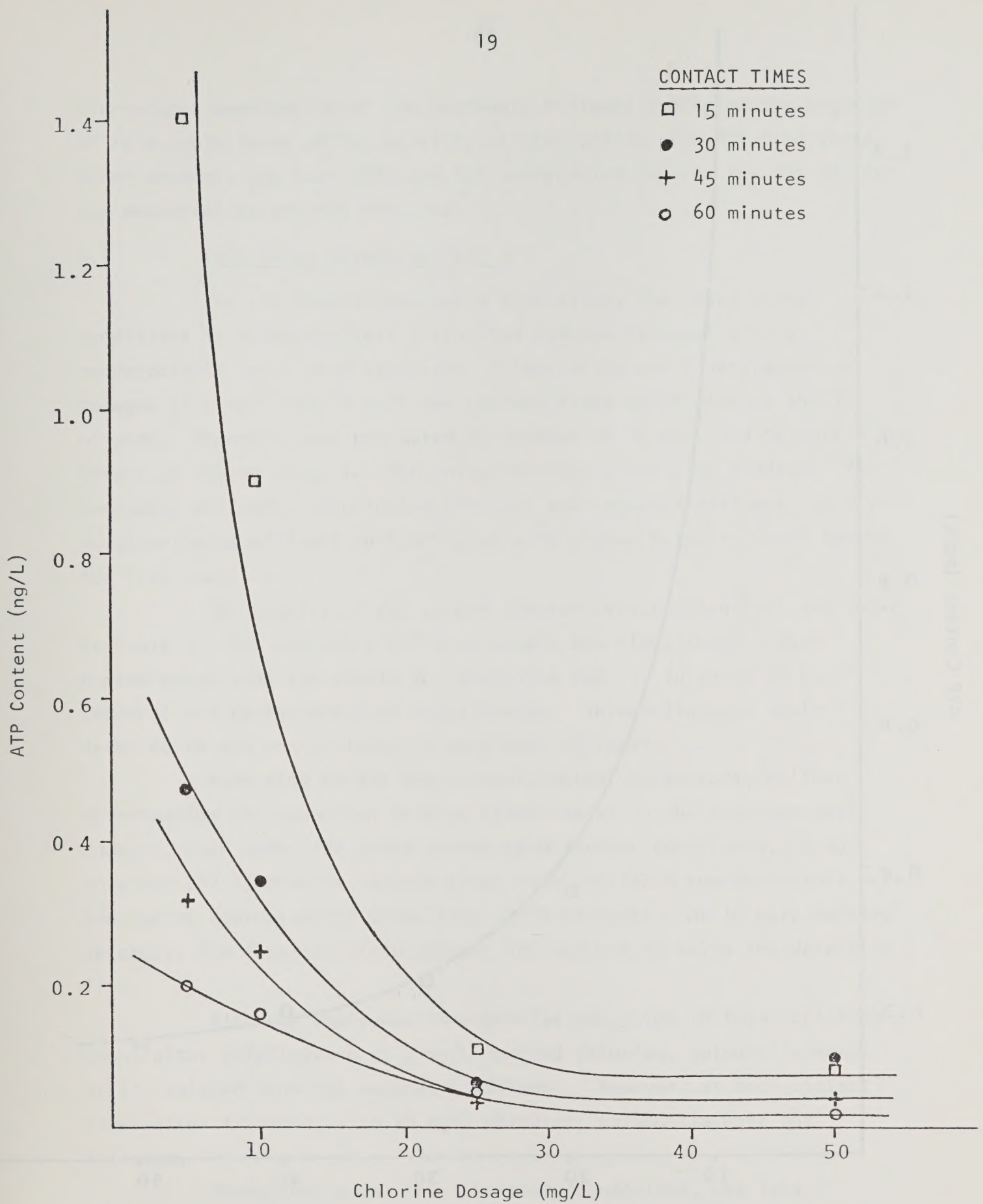


FIGURE 4. EFFECT OF CHLORINATION ON ATP CONTENT - LABORATORY SCREENING TEST 1

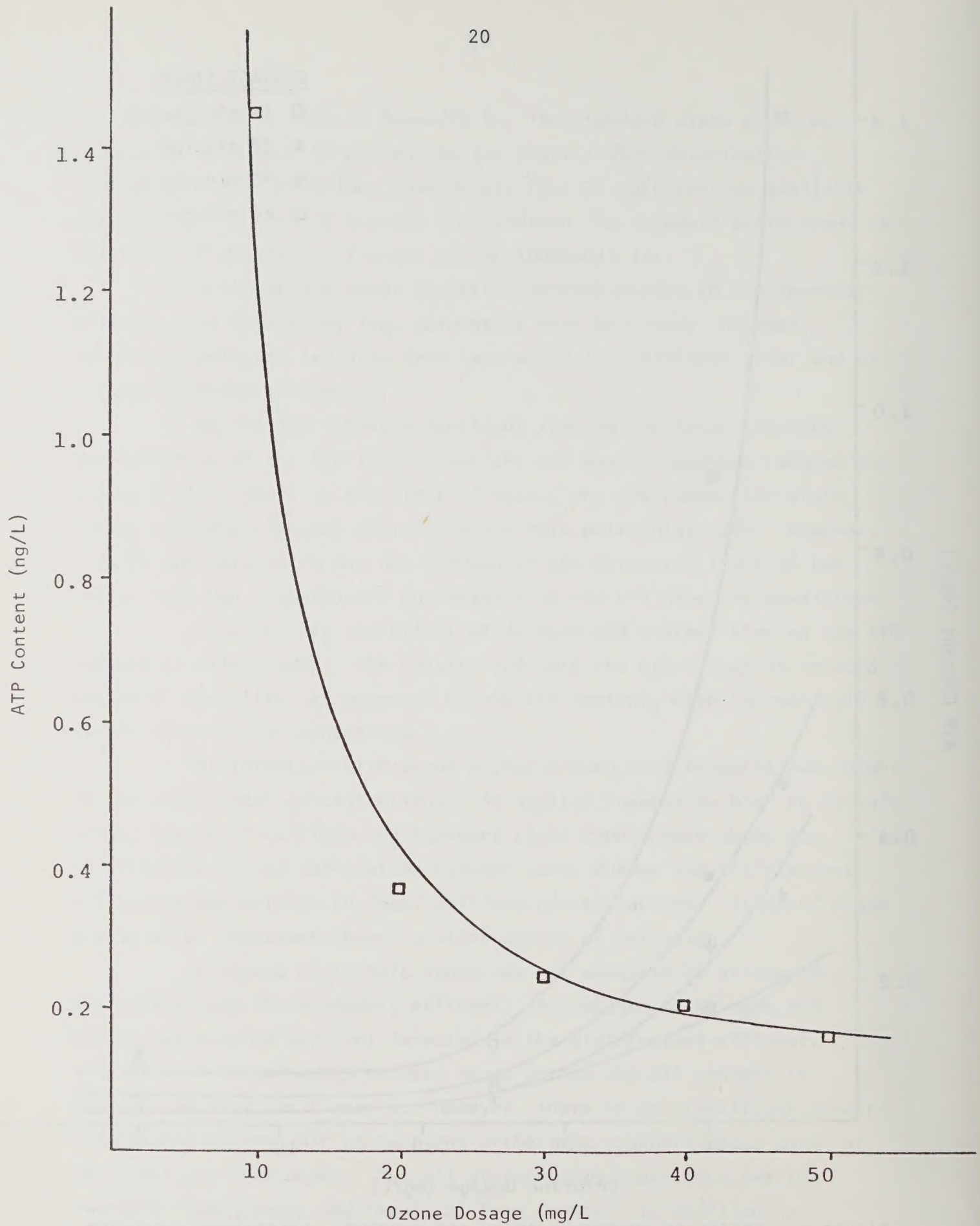


FIGURE 5. EFFECT OF OZONATION ON ATP CONTENT - LABORATORY SCREENING TEST 1

microscopic examination of the secondary effluent indicated the presence of relatively large cells, possibly chicken cells. The ATP from these other sources, may have affected the correlation between the ATP and the two bacterial parameters measured.

4.2 Laboratory Screening Test 2

For the second laboratory evaluation, the least severe conditions in screening test 1 that had reduced salmonella to a nondetectable level were assessed. Chlorination was investigated at dosages of 5 mg/L and 10 mg/L and contact times of 15 minutes and 30 minutes. Ozonation was evaluated at dosages of 20 mg/L and 30 mg/L. The effect of dosing ozone to both column diffusers was also studied. The secondary effluent, chlorinated effluent and ozonated effluent, as well as chlorinated effluent dechlorinated with sodium sulphite, were tested for fish toxicity.

The results of the second laboratory screening test are shown in Table 3. The secondary effluent sample was significantly more contaminated than the sample for screening test 1, in terms of both chemical and bacteriological constituents. Salmonella were again detected in the non-disinfected secondary effluent.

According to all the microbiological parameters, neither chlorination nor ozonation were as effective as in the previous test. However, even under the least severe chlorination conditions, 5 mg/L chlorine and 15 minutes contact time, fecal coliform concentrations were reduced by approximately three logs (99.9 percent). At 10 mg/L applied chlorine, the fecal coliform content was reduced to below the detection limit.

Although there was an extensive reduction in fecal coliform count after chlorination at 5 mg/L applied chlorine, salmonella were still isolated from the secondary effluent. However, at both contact times after treatment with 10 mg/L chlorine, salmonella were not detected.

Ozonation, under the laboratory conditions, was less successful than chlorination as a disinfecting procedure. Salmonella were isolated in every sample and a significant reduction was never

TABLE 3. LABORATORY EVALUATION OF DISINFECTANT EFFICIENCY SCREENING TEST 2 - DECEMBER 1, 1976

Disinfectant	Chemical Characteristics				Bacteriological Characteristics					
	Applied Dosage (mg/L)	Contact Time (min)	pH	BOD (mg/L)	Disinfectant Residual (mg/L)		Standard Plate Count (per mL)	Fecal Coliform Count (per 100 mL)	ATP Content (ng/mL)	Salmonella (presence/absence)
					Total	Free				
Control	-	-	7.6	38	-	-	430,000	78,000	44.0	Present
Chlorine	5	15	7.8	-	3.6	0.3	73,000	<100	19.0	Present
		30	7.8	30	2.9	0.2	78,000	< 10	15.0	Present
	10	15	7.8	-	5.6	0.3	TNTC	< 2	11.0	Absent
		30	7.8	25	5.1	0.3	35,000	< 2	9.5	Absent
Ozone	20	13*	7.9	33	0.20	-	600,000	17,000	29.0	Present
		>13+	7.9	22	0.16	-	280,000	6,000	23.0	Present
	30	13*	7.9	22	0.17	-	310,000	7,000	34.0	Present
		>13+	7.6	21	0.15	-	340,000	25,000	18.0	Present

* Ozone applied by means of bottom diffuser only.

+ Ozone applied by means of bottom and central diffuser.

achieved in either the standard plate count, the fecal coliform count or the ATP concentration. Dosing ozone to both column diffusers did not consistently improve the disinfection efficiency in this case.

The results of the static 96-hour pass/fail fish toxicity tests are summarized in Appendix I, Table I-1. Although there was some toxicity associated with the non-disinfected secondary effluent, chlorination significantly increased the toxicity of the waste. Mortality was increased to 100 percent after only 24 hours in the effluent treated with 10 mg/L chlorine. The lower chlorine dosage, 5 mg/L, also resulted in some increase in the toxicity of the waste.

Dechlorination with sodium sulphite reduced the toxicity of the chlorinated secondary effluent. Samples of secondary effluent chlorinated at 5 mg/L and dechlorinated with sodium sulphite showed no toxicity to the test fish during the 96-hour test period.

Ozonation of the effluent eliminated any toxicity associated with the waste during the 96-hour static tests.

4.3 Laboratory Screening Test 3

For the third laboratory screening test, the same chlorination conditions were assessed as during screening test 2. These conditions appeared to bracket the range required to reduce salmonella to a nondetectable level in the secondary effluent. However, the results of the second screening test indicated that higher dosages of ozone were required. Therefore, dosages of 30 mg/L, 40 mg/L and 50 mg/L were applied to the laboratory contact column. At the lower and middle dosages, the effect of dosing ozone at both diffusers was assessed.

The secondary effluent sample used for the third laboratory test was more contaminated than either of the previous samples, due to the mechanical problems experienced at the treatment plant. The chemical constituents, BOD, suspended solids and ammonia-nitrogen, were present in significantly higher concentrations.

Bacteriological concentrations were comparable to those determined in the second laboratory test. Salmonella were detected in the secondary effluent.

The results of the third screening test are summarized in Table 4. Chlorination of the secondary effluent resulted in large reductions of the bacteriological concentrations. At the least severe conditions, a three-log reduction (99.9 percent) was attained in the fecal coliform concentration. Under the most severe conditions, the fecal coliform count was reduced to 2 per 100 mL.

Although the application of 5 mg/L chlorine resulted in a three-log reduction in the fecal coliform count, the conventional indicator of pathogenic organisms, salmonella, was still isolated from the treated samples.

When 10 mg/L chlorine was applied to the effluent sample, salmonella were not detected after a contact time of 15 minutes. However, salmonella were isolated from the sample after 30 minutes contact time. The limitations of the positive/negative test procedure are evident in this case. Variations in the detection of salmonella due to sampling become more significant when the salmonella population in the sample is reduced to the detection limit of the assay.

Disinfection by ozonation was again less successful than chlorination. Fecal coliform concentrations were significantly higher than in the chlorination trials despite the higher dosages of ozone applied. The results, however, suggest that improved treatment efficiency can be obtained by applying ozone to more than one point in the contact column. The high organic content of the secondary effluent probably reduced the efficiency of the ozonation process. Although the higher ozone dosages appeared to reduce the standard plate counts and fecal coliform counts to a greater extent than in screening test 2, salmonella were detected in all ozonated samples.

The secondary effluent for screening test 3 was highly toxic. The results of the fish toxicity tests are summarized in Appendix I, Table I-2. One hundred percent mortality of the test fish resulted after only eight hours of contact. High ammonia-nitrogen concentration, 16.7 mg/L, was probably responsible for the lethal effect of the waste. None of the treatment methods affected the ultimate toxicity of the waste after 96-hours, although the rate of fish mortality did vary from sample to sample.

TABLE 4. LABORATORY EVALUATION OF DISINFECTANT EFFICIENCY SCREENING TEST 3 - DECEMBER 14, 1976

Disinfectant	Applied Dosage (mg/L)	Contact Time (min)	Chemical Characteristics				Bacteriological Characteristics			
			pH	BOD (mg/L)	Disinfectant Residual (mg/L)		Standard Plate Count (per mL)	Fecal Coliform Count (per 100 mL)	ATP Content (ng/mL)	Salmonella (presence/absence)
Control	-	-	7.2	92	-	-	630,000	88,000	80.0	Present
Chlorine	5	15	7.5	-	3.1	0.4	10,200	150	46.0	Present
		30	7.2	79	2.9	0.4	10,300	36	37.0	Present
	10	15	7.4	-	5.7	0.4	97,000	6	22.0	Absent
		30	7.5	78	5.0	0.4	25,000	2	17.0	Present
Ozone	30	>13 ⁺	7.0	90	1.38	-	43,000	7,000	36.0	Present
		13*	7.0	91	1.51	-	63,000	1,600	28.0	Present
	40	>13 ⁺	7.0	80	1.72	-	11,600	500	15.0	Present
		13 ⁺	6.9	92	1.59	-	28,000	600	31.0	Present

* 0 zone applied by means of bottom diffuser only.

+ 0 zone applied by means of bottom and central diffuser.

5 RESULTS OF PHASE II - PERFORMANCE OF SELECTED TREATMENT PLANTS

The poultry processing effluent treatment plants maintain minimal operational records. At Plants 1 and 2, effluent flows are not monitored. Estimates of the treatment plant loadings are obtained from the raw water usage in the process. Sampling and analysis of plant performance is infrequent. Flow records were available for the pretreatment facility at Plant 3. More substantial records of the performance of the municipal water pollution control plant receiving the poultry plant effluent are maintained.

The treatment facilities are described in the following sections. The available data regarding plant operation and performance are reviewed. The results of the one-week monitoring program are presented in detail.

5.1 Plant 1 - Secondary Treatment Facility

Plant 1 processes chickens and turkeys at a rate of approximately 6,000 birds per hour, equivalent to about one million pounds (live weight) per week. The production schedule is normally eight hours per day, five days a week. A regular cleaning of the plant is carried out at the end of each daily production shift. An intensive plant cleaning is normally scheduled at the end of each production week.

Process waste flows average approximately 500,000 lgp/d (2280 m³/d). The process wastes are directed to a solids recovery facility where much of the grease and solid matter is removed by screens and a dissolved air flotation system. Effluent from the solids recovery plant is pumped to the waste treatment facility. Basic design criteria and operating conditions for the treatment facility are summarized in Table 5.

The waste is screened prior to biological treatment by four vibrating Sweco screen separators, each capable of handling flows of 300 lgp/m (22.8 L/s). The liquid effluent from the screens is diverted, through a splitter box, to two 1.77 MIG (0.54 x 10⁴ m³) aeration basins. One aeration cell is equipped with a 75 hp (56 kW) mechanical surface aerator. In the second cell, the 75 hp (56 kW) aerator has been replaced with a 100 hp (74.6 kW) aerator to improve oxygen transfer.

TABLE 5. PLANT 1 WASTE TREATMENT SYSTEM BASIC DESIGN AND OPERATING CONDITIONS

Average Process Effluent Flow Rate	= 500,000 lgp/d (2280 m ³ /d)
Screening Facilities:	Four Sweco vibrating screens
Aeration Tanks:	Volume = 2.34 MIG (1.07 × 10 ⁴ m ³)
	Nominal Retention Time = 4.7 days
	Average Organic Loading = 0.05 $\frac{\text{lb BOD/day}}{\text{lb MLSS}}$
	(0.05 $\frac{\text{kg BOD/day}}{\text{kg MLSS}}$)
	Oxygen Transfer Equipment:
	1 - 75 hp (56 kW) mechanical aerator
	1 - 100 hp (74.6 kW) mechanical aerator
Secondary Clarification:	Configuration: 40-foot (12.2-m) diameter
	Average overflow rate = 400 lgp/d/ft ²
	(19.6 m ³ /m ² ·d)
Polishing Lagoon"	Surface Area = 4 acres (1.6 ha)
	Average Depth = 6 feet (1.8 m)
Chlorination:	Average Contact Time = 45 minutes
	Applied Dosage = 12 mg/L available chlorine

Retention time in the aeration system is in excess of four days at the average hydraulic loading. Design organic loading of the system is about 0.05 lb BOD/lb MLSS/day (0.05 kg BOD/kg MLSS/day).

Biological solids are removed in a single 40-foot (12.2 m) diameter circular clarifier which provides an average overflow rate of about 400 l/gpd/ft² (19.6 m³/m² · d). Settled sludge is returned to the influent splitter box for distribution to the two aeration tanks. No facilities are provided for wasting sludge from the system.

Secondary clarifier effluent is polished in a 4-acre facultative lagoon. The lagoon effluent is chlorinated by the addition of sodium hypochlorite at an average dosage of approximately 12 mg/L available chlorine prior to discharge to the receiving stream.

Available data from previous sampling programs indicate that the biological system operates at approximately the design organic loading of 0.05 lb BOD/lb MLSS/day (0.05 kg BOD/kg MLSS/day), based on an average influent BOD of 800 mg/L, mixed liquor concentrations of about 3,500 mg/L and average hydraulic loading. The screened waste, from previous data, showed a high degree of variability. BOD concentration ranged from 240 to 2,150 mg/L and suspended solids from 140 to 1,000 mg/L.

In general, the final effluent quality from the treatment system has been acceptable. Based on about 20 samplings during 1975, average lagoon effluent quality was 20 mg/L BOD and 30 mg/L suspended solids. However, the secondary effluent contained an average of 60 mg/L BOD and 75 mg/L suspended solids. Bulking sludge problems have been observed at the plant and have resulted in the discharge of quantities of biological solids to the polishing lagoon. In the fall of 1976, a return sludge chlorination system was installed in an attempt to control the growth of filamentous organisms.

The performance of the plant during the one-week sampling period was similar to the previous experiences. The chemical characteristics of the waste streams are summarized in Table 6. Composite samples of the screened waste showed only small daily variation in the contaminant concentrations. Secondary effluent contained high

TABLE 6. WASTEWATER TREATMENT SYSTEM PERFORMANCE - PLANT 1 CHEMICAL CHARACTERISTICS OF WASTE STREAMS

Sampling Date	Stream	Avg pH	Avg Temp (°C)	BOD (mg/L)		Suspended Solids (mg/L)	Total Phosphorus (mg/L P)	Kjeldahl Nitrogen (mg/L)	Ammonia Nitrogen (mg/L)	Oil and Grease (mg/L)
				Total	Soluble					
9/11/76	Screened Waste	7.6	25	610	220	276	11.4	95.2	19.8	32
	Secondary Effluent	7.9	7	460	34	1,484	-	-	-	20
	Lagoon Effluent	7.5	2	12	4	24	1.9	72.2	6.4	7
	Chlorinated Effluent	8.2	3	-	-	-	-	-	-	-
10/11/76	Screened Waste	6.9	21	481	204	380	17.3	98.0	10.7	61
	Secondary Effluent	7.1	7	281	16	696	-	-	-	13
	Lagoon Effluent	7.5	2	9	5	22	2.0	17.9	6.9	21
	Chlorinated Effluent	-	-	-	-	-	-	-	-	-
11/11/76	Screened Waste	8.3	17	446	191	280	8.1	84.0	24.7	92
	Secondary Effluent	8.3	4	245	46	556	-	-	-	78
	Lagoon Effluent	8.5	1	16	9	18	2.0	12.2	9.7	21
	Chlorinated Effluent	-	-	-	-	-	-	-	-	-

TABLE 6 (CONT'D)

Sampling Date	Stream	Avg pH	Avg Temp (°C)	BOD (mg/L)	Suspended Solids (mg/L)	Total Phosphorus (mg/L P)	Kjeldahl Nitrogen (mg/L)	Ammonia Nitrogen (mg/L)	Oil and Grease (mg/L)
15/11/76	Screened Waste	8.1	21	670	432	7.7	89.6	14.0	164
	Secondary Effluent	7.9	3	25	34	-	-	-	1
	Lagoon Effluent	8.0	1	11	21	2.8	12.8	10.5	2
	Chlorinated Effluent	-	-	-	-	-	-	-	-
16/11/76	Screened Waste	7.9	-	550	308	6.6	67.2	11.5	131
	Secondary Effluent	7.4	4	47	112	-	-	-	11
	Lagoon Effluent	7.8	1	11	23	3.0	10.5	7.5	2
	Chlorinated Effluent	7.5	0	-	-	-	-	-	-
Average	Screened Waste	7.8	21	551	355	102	86.8	16.1	96
	Secondary Effluent	7.7	5	212	576	-	-	-	25
	Lagoon Effluent	7.9	1	12	22	2.3	25.1	8.2	11
	Chlorinated Effluent	7.9	2	-	-	-	-	-	-

solids concentrations, particularly during the first three days of sampling. Despite the addition of chlorine to the return sludge, poor sludge settleability was evident, as noted in the summary of plant operating conditions in Table 7. Sludge settleability improved noticeably on the last two days of sampling, a Monday and Tuesday. The reduced organic load on the system during the weekend was probably partially responsible for this improvement in sludge settling properties.

Biologically, the system performed adequately during this period. Soluble BOD was reduced from 208 mg/L in the screened waste to 21 mg/L in the secondary effluent. Dissolved oxygen concentrations in excess of 6 mg/L were maintained in the aeration basin.

The polishing lagoon significantly improved the quality of the treated waste, particularly in regard to suspended matter. It is evident, however, that problems will result in the lagoon eventually due to the accumulation of biological solids.

The bacteriological characteristics of the Plant 1 waste streams are summarized in Table 8. Salmonella were detected in the effluent after biological treatment, and in the discharge of the polishing lagoon. Chlorination at 12 mg/L did not eliminate salmonella from the final effluent.

The polishing lagoon did result in a significant decrease in the fecal coliform content of the secondary effluent. Very little further reduction was attained by chlorination of the lagoon effluent.

5.2 Plant 2 - Tertiary Treatment Facility

Plant 2 processes chickens at a rate of 2,500 birds per hour, equivalent to about 400,000 pounds (181,000 kg) (live weight) per week. As at Plant 1, the production schedule is normally eight hours per day, five days per week, dependent on the supply. Thorough cleaning of the process area occurs at the end of each daily production shift.

Process waste flows average approximately 100,000 lpgd ($456 \text{ m}^3/\text{d}$). Extremely stringent effluent criteria for the plant require a complex tertiary treatment system. A schematic flowsheet of the facility at Plant 2 is shown in Figure 6. Basic design criteria and operating conditions for the treatment system are summarized in Table 9.

TABLE 7. WASTEWATER TREATMENT PLANT OPERATING CONDITIONS POULTRY PROCESSING PLANT I

Date	Estimated Flow (gpd) (m ³ /s)	Aeration Tank Conditions					Comments on Plant Operation
		pH	Temp (°C)	MLSS (mg/L)	Dissolved Oxygen (mg/L)	Sludge Settleability (percent)	Organic Loading lb BOD/lb MLSS/day (kg BOD/kg MLSS/day)
9/11/76	480,000 (2.5x10 ⁻²)	7.3	6.5	2,100	6.3	89	0.06
10/11/76	464,000 (2.4x10 ⁻²)	6.1	8.0	2,100	6.1	88	0.05
11/11/76	532,000 (2.8x10 ⁻²)	7.5	8.0	1,400	6.7	65	0.07
15/11/76	500,000 (2.6x10 ⁻²)	7.5	8.0	1,750	7.5	33	0.08
16/11/76	580,000 (3.1x10 ⁻²)	9.0	7.0	1,850	6.4	30	0.07
Average	500,000 (2.6x10 ⁻²)	7.5	7.5	1,850	6.6	60	0.07
							-

Chlorinating Return
Sludge for Control
of BulkingChlorinating Return
Sludge for Control
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TABLE 8. WASTEWATER TREATMENT SYSTEM PERFORMANCE - PLANT 1
BACTERIOLOGICAL CHARACTERISTICS OF WASTE STREAMS

Sampling Date	Stream	Fecal Coliform Count (per 100 mL)	Salmonella (presence/absence)
9/11/76	Secondary Effluent	94,000	Present
	Lagoon Effluent	900	Present
	Chlorinated Effluent	1,200	Present
10/11/76	Secondary Effluent	111,000	Present
	Lagoon Effluent	2,700	Present
	Chlorinated Effluent	1,600	Present
11/11/76	Secondary Effluent	40,000	Present
	Lagoon Effluent	1,300	Present
	Chlorinated Effluent	1,200	Present
15/11/76	Secondary Effluent	3,900	Present
	Lagoon Effluent	170	Present
	Chlorinated Effluent	180	Present

TABLE 8 (CONT'D)

Sampling Date	Stream	Fecal Coliform Count (per 100 mL)	Salmonella (presence/absence)
16/11/76	Secondary Effluent	13,000	Present
	Lagoon Effluent	1,040	Present
	Chlorinated Effluent	110	Present
Average	Secondary Effluent	29,200*	-
	Lagoon Effluent	890*	-
	Chlorinated Effluent	590*	-

* Geometric Mean

⊗ Sample Points

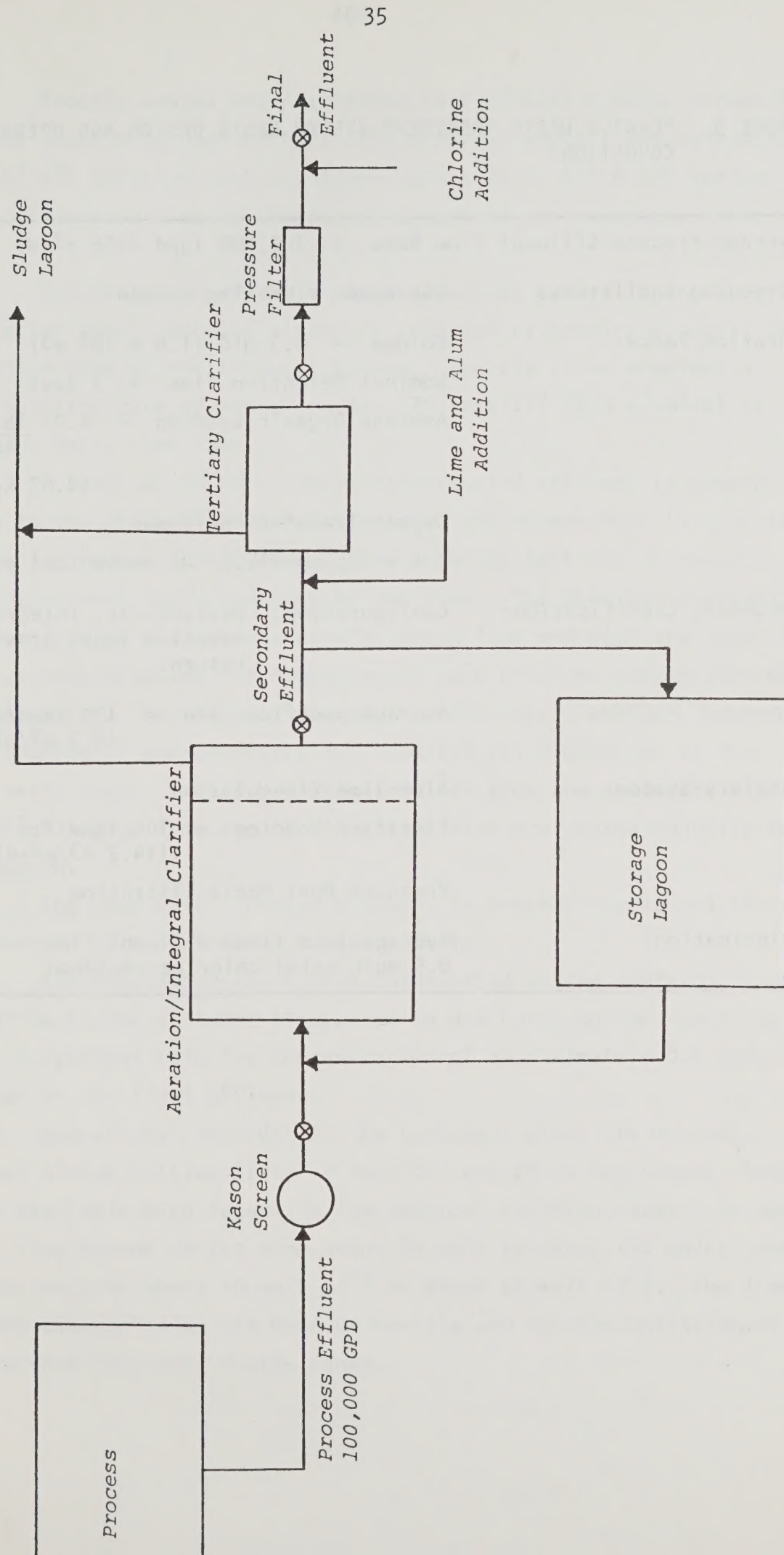


FIGURE 6. SCHEMATIC FLOWSHEET OF PLANT 2 WASTE TREATMENT SYSTEM

TABLE 9. PLANT 2 WASTE TREATMENT SYSTEM BASIC DESIGN AND OPERATING CONDITIONS

Average Process Effluent Flow Rate = 100,000 lpgd (456 m ³ /d)	
Screening Facilities:	One Kason vibrating screen
Aeration Tanks:	Volume = 0.3 MIG (1.4 x 10 ³ m ³)
	Nominal Retention Time = 3 days
	Average Organic Loading = 0.03 $\frac{\text{lb BOD/day}}{\text{lb MLSS}}$
	(0.03 kg BOD/kg MLSS/day)
Oxygen Transfer Equipment:	
1 - 25 hp (18.6 kW) mechanical aerator	
Secondary Clarification:	Configuration: rectangular, integral with aeration tank, gravity sludge return.
Average overflow rate = 170 lpgd/ft ² (8.3 m ³ /m ² ·d)	
Tertiary System:	Alum-lime flocculation
	Clarifier Loading = 300 lpgd/ft ² (14.7 m ³ /m ² ·d)
	Pressure Dual Media Filtration
Chlorination:	Average into final effluent line 0.5 mg/L total chlorine residual

Process wastes are discharged to a vibrating Kason screen for removal of gross suspended matter. The screened waste flows to a 0.3 MIG ($1.4 \times 10^3 \text{ m}^3$) aeration tank, equipped with a 25 hp (18.6 kW) surface aerator. Retention time in the aeration tank is approximately three days.

Sedimentation of the biological solids occurs in an integral clarification zone. Settled sludge is returned by gravity directly to the aeration zone of the integral system. The clarifier provides a surface settling rate of approximately $170 \text{ lgp}/\text{ft}^2$ ($8.3 \text{ m}^3/\text{m}^2 \cdot \text{d}$) at the average daily flow rate.

A fraction of the biologically-treated effluent is pumped directly to the chemical treatment system. The excess flow is diverted to a storage lagoon and is returned to the aeration tank for ultimate chemical treatment during periods of low flow. The chemical treatment system consists of a flash-mix tank to which lime and alum are added for phosphorus precipitation. A flocculation tank provides coagulation of suspended matter. Solids are removed in a tertiary clarifier, operated at a surface loading of approximately $300 \text{ lgp}/\text{ft}^2$ ($14.7 \text{ m}^3/\text{m}^2 \cdot \text{d}$) at the average daily flow. Excess biological solids from the secondary clarifier and chemical sludge from the tertiary clarifier are wasted manually to a sludge lagoon.

The chemically treated effluent is prechlorinated and residual solids removed in a dual-media pressure filter.

The treated waste is then chlorinated by the addition of sodium hypochlorite to the effluent line prior to discharge to the receiving stream. A residual chlorine concentration of approximately 0.5 mg/L is maintained in the final effluent.

Operational records for the treatment plant are minimal. Biological sludge settleability is recorded and pH is monitored. Some data are available with regard to the chemical addition rates. It appears that the lime dosage varies from about 60 mg/L to about 250 mg/L . Alum dosage varies from about 10 mg/L Al^{+3} to about 25 mg/L Al^{+3} . The lime slurry and alum solution are made up on-site and the concentration of the feed solutions vary over a wide range.

Analysis of about 20 final effluent samples during 1976 indicated that the plant, on the average, performs very well although high suspended solids concentrations occur occasionally. On the average, the effluent contains less than 5 mg/L BOD, 20 mg/L suspended solids and 0.3 mg/L phosphorus. No up-to-date data were available regarding the quality of the process wastes.

During the one-week sampling period, chlorine was dosed only after the filtration process. Problems also developed with the alum and lime dosing systems. Low lime dosages were applied early in the sampling week and the alum and lime systems were shut down while the tanks were cleaned and refilled.

The chemical characteristics of the waste streams are summarized in Table 10. The raw waste strength was relatively constant. Removal of organic contaminants in the biological system was adequate; however, high concentrations of solids were discharged from the tertiary clarifier. The final effluent contained relatively low concentrations of nutrients. Average total phosphorus concentration was 2.2 mg/L, due to the problems with the chemical feed system; however, ammonia nitrogen content averaged 0.2 mg/L. The long retention time and dissolved oxygen concentrations in excess of 4 mg/L in the biological reactor result in good nitrification of the process wastes. Subsequent nitrate and nitrite nitrogen analyses, added during the Phase III program, confirmed these observations.

The operating conditions for the biological system are summarized in Table 11. The biological sludge exhibited good settling characteristics. The average organic loading on the system was 0.03 lb BOD/lb MLSS/day (0.03 kg BOD/kg MLSS/day). Relatively high mixed liquor concentrations were carried in the biological system during the sampling period.

The bacteriological characteristics of the waste streams are summarized in Table 12. The tertiary treatment system reduced, significantly, the fecal coliform content of the waste. A further reduction was evident after chlorination despite the relatively short contact time provided in the discharge pipe. Chlorinated effluent fecal coliform counts were comparable to those at Plant 1.

TABLE 10. WASTEWATER TREATMENT SYSTEM PERFORMANCE - PLANT 2 CHEMICAL CHARACTERISTICS OF WASTE STREAMS

Sampling Date	Stream	Avg pH	Avg Temp (°C)	BOD (mg/L)		Suspended Solids (mg/L)	Total Phosphorus (mg/L P)	Kjeldahl Nitrogen (mg/L)	Ammonia Nitrogen (mg/L)	Oil and Grease (mg/L)
				Total	Soluble					
18/11/76	Screened Waste	7.6	14	480	142	427	17.3	84.0	18.9	79
	Secondary Effluent	7.6	3	24	4	38	-	-	-	1
	Tertiary Effluent	8.2	4	6	3	37	1.2	4.5	0.1	1
	Chlorinated Effluent	8.7	5	-	-	-	-	-	-	-
19/11/76	Screened Waste	7.3	16	398	135	264	15.6	67.8	9.1	133
	Secondary Effluent	6.5	4	10	4	39	-	-	-	1
	Tertiary Effluent	6.0	4	5	3	46	1.8	3.4	0.1	2
	Chlorinated Effluent	7.5	6	-	-	-	-	-	-	-
22/11/76	Screened Waste	7.3	14	425	158	292	7.3	62.2	4.0	65
	Secondary Effluent	6.2	3	19	9	24	-	-	-	1
	Tertiary Effluent	9.2	3	9	6	22	1.4	3.9	0.7	1
	Chlorinated Effluent	8.8	3	-	-	-	-	-	-	-

TABLE 10. WASTEWATER TREATMENT SYSTEM PERFORMANCE - PLANT 2 CHEMICAL CHARACTERISTICS OF WASTE STREAMS (CONT'D)

Sampling Date	Stream	Avg pH	Avg Temp (°C)	BOD (mg/L)		Suspended Solids (mg/L)	Total Phosphorus (mg/L P)	Kjeldahl Nitrogen (mg/L)	Ammonia Nitrogen (mg/L)	Oil and Grease (mg/L)
				Total	Soluble					
23/11/76	Screened Waste	7.5	12	425	155	276	7.7	70.6	3.4	126
	Secondary Effluent	7.1	3	20	5	36	-	-	-	1
	Tertiary Effluent	8.1	3	16	4	58	5.1	5.0	0.1	1
	Chlorinated Effluent	7.2	3	-	-	-	-	-	-	-
24/11/76	Screened Waste	7.3	14	415	135	252	8.6	63.3	3.5	63
	Secondary Effluent	6.5	1	15	2	32	-	-	-	2
	Tertiary Effluent	10.8	2	5	3	32	1.5	1.7	0.2	2
	Chlorinated Effluent	10.6	2	-	-	-	-	-	-	-
Average	Screened Waste	7.4	14	428	145	193	11.3	69.6	7.8	93
	Secondary Effluent	6.8	3	18	5	34	-	-	-	1
	Tertiary Effluent	8.5	3	8	4	39	2.2	3.7	0.2	1
	Chlorinated Effluent	8.6	4	-	-	-	-	-	-	-

TABLE 11. WASTEWATER TREATMENT PLANT OPERATING CONDITIONS - POULTRY PROCESSING PLANT 2

Date	Estimated Flow (GPD) (m ³ /s)	Aeration Tank Conditions					Organic Loading		Comments on Plant Operation
		pH	Temp (°C)	MLSS (mg/L)	Dissolved Oxygen (mg/L)	Sludge Settleability (percent)	1b BOD/kg (kg BOD/kg MLSS/day)	1b BOD/kg MLSS/day	
18/11/76	105,000 (5.5x10 ⁻³)	7.6	4.0	4,430	5.0	23	0.04		-
19/11/76	105,000 (5.5x10 ⁻³)	7.6	7.0	5,080	4.8	21	0.03		Low Lime Addition Rate
22/11/76	97,500 (5.1x10 ⁻³)	6.3	3.0	4,820	9.4	23	0.03		-
23/11/76	97,500 (5.1x10 ⁻³)	7.0	4.0	4,350	5.8	22	0.03		Cleaning and Filling Lime and Alum Tanks
24/11/76	97,500 (5.1x10 ⁻³)	6.1	5.0	4,970	6.3	23	0.03		-
Average	100,000 (5.3x10 ⁻³)	6.9	4.5	4,700	6.3	22	0.03		-

TABLE 12. WASTEWATER TREATMENT SYSTEM PERFORMANCE - PLANT 2
BACTERIOLOGICAL CHARACTERISTICS OF WASTE STREAMS

Sampling Date	Stream	Fecal Coliform Count (per 100 mL)	Salmonella (presence/absence)
18/11/76	Secondary Effluent	148,000	Present
	Tertiary Effluent	91,000	Present
	Chlorinated Effluent	4,400	Present
19/11/76	Secondary Effluent	161,000	Present
	Tertiary Effluent	12,000	Present
	Chlorinated Effluent	20	Absent
22/11/76	Secondary Effluent	67,000	Present
	Tertiary Effluent	8,300	Present
	Chlorinated Effluent	1,310	Present
23/11/76	Secondary Effluent	230,000	Present
	Tertiary Effluent	180,000	Present
	Chlorinated Effluent	2,100	Present

TABLE 12 (CONT'D)

Sampling Date	Stream	Fecal Coliform Count (per 100 mL)	Salmonella (presence/absence)
24/11/76	Secondary Effluent	130,000	Present
	Tertiary Effluent	12,000	Present
	Chlorinated Effluent	1,340	Present
Average	Secondary Effluent	136,700*	-
	Tertiary Effluent	28,700*	-
	Chlorinated Effluent	800*	-

* Geometric Mean

Salmonella were present in all secondary effluent samples. The tertiary treatment process did not eliminate salmonella from the process wastes. Except for one occasion, when fecal coliforms were reduced to a very low level (20 counts per 100 mL), the chlorination process was unsuccessful in preventing salmonella discharges in the final effluent.

5.3 Plant 3 - Pretreatment Facility

Plant 3 handles primarily broiler chickens with occasional periods of turkey and fowl processing. Average throughput for the plant is about 3,600 birds per hour, equivalent to about 1.2 million pounds (5.5×10^5 kg) (live weight) per week based on the normal 16 hours per day, five days per week operation. Plant cleaning is normally scheduled after each production day with intensive cleaning of the process area after the production week.

Average daily wastewater from the poultry processing plant is approximately 0.5 lmgd ($2,280 \text{ m}^3/\text{day}$). After gross solids recovery, the process effluent is discharged to a gravity-settling tank for removal of settleable solids and grease. The pretreated industrial waste is discharged to the sanitary sewer system for treatment at the municipal water pollution control plant. A schematic representation of the combined system is provided in Figure 7. The design and operating conditions are summarized in Table 13.

The design loading of the municipal water pollution control plant is 1.0 lmgd ($4,560 \text{ m}^3/\text{day}$) and 2,500 lb BOD/day (1,100 kg BOD/day). Primary clarification of the raw waste is provided by two rectangular settling tanks, each 980 square feet (91 m^2). Design surface settling rate in the primary clarifiers is about 500 lmgd/ft^2 ($24.5 \text{ m}^3/\text{m}^2 \cdot \text{d}$).

The aeration system provides a design retention time of approximately seven hours in two parallel basins. Dissolved oxygen is supplied by a diffused air system designed to provide 1,200 cubic feet per pound ($75 \text{ m}^3/\text{kg}$) of BOD loading. Biological solids are removed in two secondary clarifiers at a design surface settling rate of

⊗ Sample Points

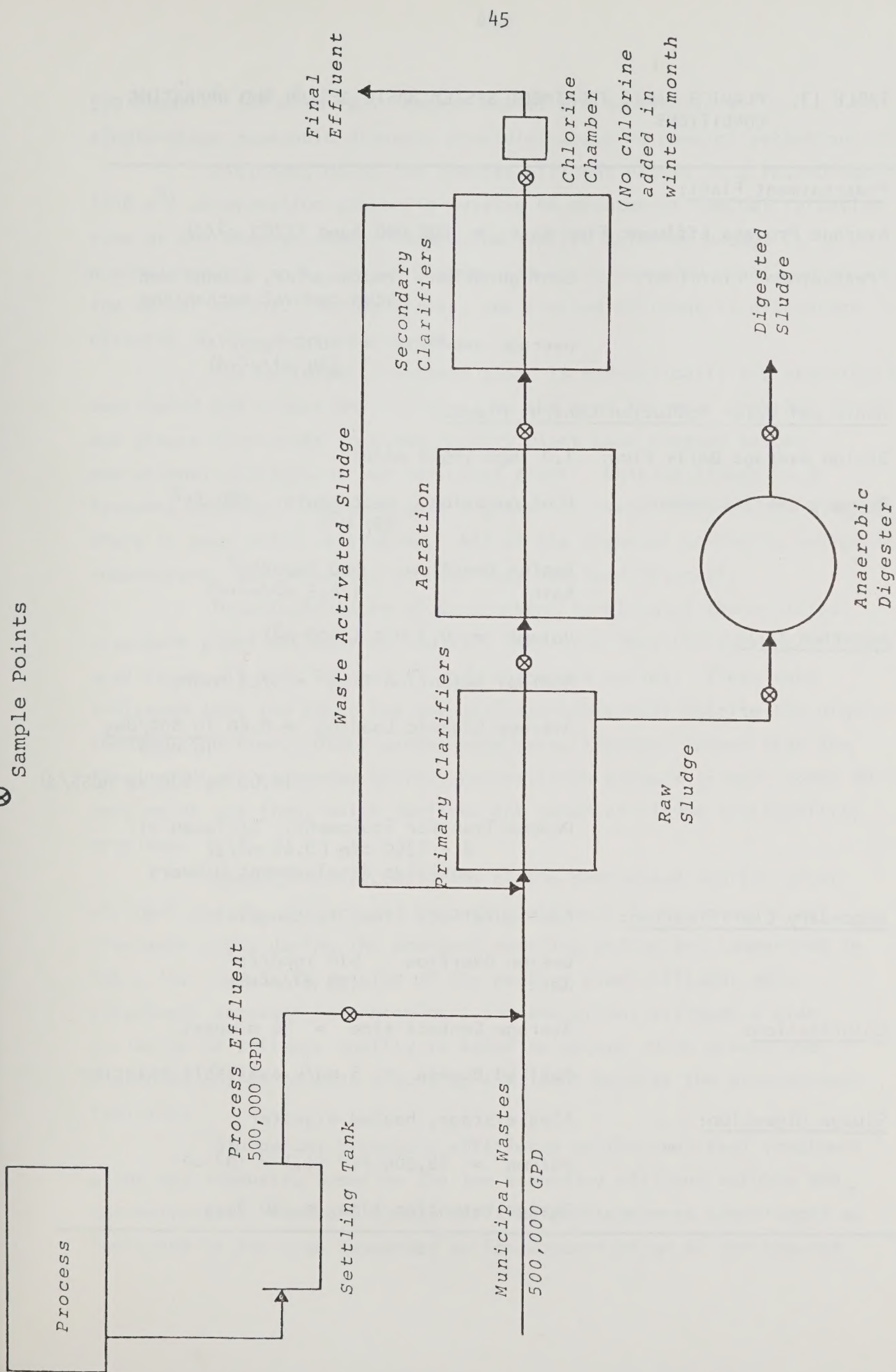


FIGURE 7. SCHEMATIC FLOWSHEET OF PLANT 3 WASTE TREATMENT SYSTEM

TABLE 13. PLANT 3 WASTE TREATMENT SYSTEM BASIC DESIGN AND OPERATING CONDITIONS

Pretreatment Plant:Average Process Effluent Flow Rate = 500,000 lpgd ($2280 \text{ m}^3/\text{d}$)

Pretreatment clarifier: Configuration: rectangular, sludge and scum removal mechanisms

average overflow = 1000 lpgd/ft^2
($49 \text{ m}^3/\text{m}^2 \cdot \text{d}$)Municipal Water Pollution Control Plant:Design Average Daily Flow: 1.0 lmgd ($4560 \text{ m}^3/\text{d}$)Primary Clarification: Configuration: rectangular, 980 ft^2
(91 m^2)Design Overflow Rate: 500 lpgd/ft^2
($24.5 \text{ m}^3/\text{m}^2 \cdot \text{d}$)Aeration Tanks:Volume = 0.3 MIG (1400 m^3)

Nominal Retention Time = 7.3 hours

Average Organic Loading = $0.60 \frac{\text{lb BOD/day}}{\text{lb MLSS}}$
($0.60 \text{ kg BOD/kg MLSS/d}$)Oxygen Transfer Equipment: Diffused air
2 - 1350 cfm ($0.64 \text{ m}^3/\text{s}$)
positive displacement blowersSecondary Clarification: Configuration: two, rectangularDesign Overflow Rate: 570 lpgd/ft^2
($28 \text{ m}^3/\text{m}^2 \cdot \text{d}$)Chlorination:

Average Contact time = 46 minutes

Applied Dosage = 5 mg/L available chlorine

Sludge Digestion:

Single-stage, heated digester

Volume = $38,000 \text{ ft}^3$ ($1.1 \times 10^3 \text{ m}^3$)

Design retention time = 40 days

570 l/gpd/ft² (28 m³/m²·d). Excess solids are handled in a single-stage anaerobic digester providing about 40 days of retention.

Disinfection of the treated effluent occurs in a 32,000 lgal (146 m³) chlorination chamber providing 46 minutes of nominal retention time at the average design flow. The applied chlorine dosage is approximately 5 mg/L; however, chlorination is normally practiced only in the warmer months. During winter, the treated effluent is discharged directly to the receiving stream.

The municipal treatment plant is hydraulically and organically overloaded and expansion is planned in the near future. High BOD loads and grease discharges from the poultry plant have created severe operational problems at the municipal plant. Bulking sludge is a frequent problem. The anaerobic digester is overloaded and, as a result, there is poor solid separation. All of the digester contents, including supernatant, are presently trucked away for land disposal.

Ontario Ministry of Environment sampling of the municipal treatment plant effluent during 1976 indicated that the average effluent quality was 13 mg/L BOD and 13 mg/L suspended solids. These data indicated that the plant has operated extremely well despite the high loading condition. Other performance data, however, showed that the final effluent suspended solids concentration exceeds 15 mg/L about 80 percent of the time, which confirms the observed sludge settleability problems.

Chemical characteristics of the pretreated poultry plant effluent and the primary and secondary effluent from the municipal treatment plant during the one-week sampling period are summarized in Table 14. Composite samples of the poultry plant effluent were relatively constant in contaminant concentration, although a wide variation in effluent quality is known to occur. High grease and suspended solids concentrations were evident despite the pretreatment facility.

Biological treatment efficiency at the municipal treatment plant was adequate, based on the low secondary effluent soluble BOD concentration. However, sludge settling problems were experienced as indicated by the high suspended solids concentration of the treated

TABLE 14. WASTEWATER TREATMENT SYSTEM PERFORMANCE - PLANT 3 CHEMICAL CHARACTERISTICS OF WASTE STREAMS

Sampling Date	Stream	Avg pH	Avg Temp (°C)	BOD Total (mg/L)	Soluble (mg/L)	Suspended Solids (mg/L)	Total Phosphorus (mg/L)	Kjeldahl Nitrogen (mg/L)	Ammonia Nitrogen (mg/L)	Oil and Grease (mg/L)
6/12/76	Poultry Plant Effluent	8.0	11	525	149	376	9.0	73.4	3.7	103
	Primary Effluent	7.6	11	149	79	194	8.3	45.9	10.0	40
	Secondary Effluent	7.6	10	22	5	35	3.2	13.4	6.9	3
7/12/76	Poultry Plant Effluent	7.6	11	515	181	280	7.7	68.3	6.2	90
	Primary Effluent	7.8	11	164	83	130	5.1	35.8	6.9	47
	Secondary Effluent	7.5	12	82	8	236	5.6	31.9	10.5	15
8/12/76	Poultry Plant Effluent	7.5	8	585	173	332	8.8	80.1	4.4	103
	Primary Effluent	7.5	8	200	120	284	6.7	43.1	8.6	95
	Secondary Effluent	7.5	8	24	5	46	2.3	29.1	15.2	8
9/12/76	Poultry Plant Effluent	7.4	9	563	207	468	10.3	81.2	17.3	139
	Primary Effluent	7.2	8	220	105	244	6.7	41.4	10.2	17
	Secondary Effluent	7.4	8	156	3	324	8.3	29.1	13.8	6

TABLE 14. (CONT'D)

Sampling Date	Stream	Avg pH	Avg Temp (oc)	BOD (mg/L)		Suspended Solids (mg/L)	Total Phosphorus (mg/L)	Kjeldahl Nitrogen (mg/L)	Ammonia Nitrogen (mg/L)	Oil and Grease (mg/L)
10/12/76	Poultry Plant Effluent	7.3	11	560	191	420	9.7	87.9	16.5	152
	Primary Effluent	7.4	9	240	135	248	6.9	42.0	11.0	122
	Secondary Effluent	7.5	8	60	4	36	2.1	20.7	8.5	6
Average	Poultry Plant Effluent	7.6	10	550	180	375	9.1	78.2	9.6	117
	Primary Effluent	7.5	9	195	104	220	6.7	41.6	9.3	64
	Secondary Effluent	7.5	9	69	5	135	4.3	24.8	11.0	8

discharge. As shown in Table 15, relatively low mixed liquor concentrations were maintained in the biological system. Average organic loading of the plant was approximately 0.60 lb BOD/lb MLSS/day (0.60 kg BOD/kg MLSS/d). Although adequate dissolved oxygen concentrations were maintained, the high organic loading and high influent grease concentrations made it difficult to retain solids in the aeration system.

The bacteriological characteristics of the waste are summarized in Table 16. There was no disinfection of the municipal treatment plant effluent during the study period. Therefore, relatively high fecal coliform concentrations were discharged to the receiving waters. Salmonella were isolated from all secondary effluent samples. It appears that conventional waste treatment methods are inadequate to control the discharge of salmonella to the environment.

Samples of digested and undigested sludge were also obtained for salmonella testing. As expected, all raw sludge samples showed evidence of salmonella contamination. However, the anaerobic digestion process did not eliminate salmonella from the sludge.

Salmonella were found in all digested sludge samples. The use of digested sludges from waste treatment plants handling poultry processing effluents for agricultural purposes could have serious consequences in terms of recycling pathogenic organisms in the environment. The extent of the problem cannot be defined with the limited sludge sampling involved in the experimental program. Further studies are recommended to quantify the incidence of salmonella contamination in wastewater sludges, and to determine the effect of digester design and operation on the control of pathogenic organisms such as salmonella.

TABLE 15. WASTEWATER TREATMENT PLANT OPERATING CONDITIONS - POULTRY PROCESSING PLANT 3

Date	Poultry Plant Effluent Flow l/gpd (m ³ /d)	Total WPCP Flow (lmgd)	Aeration Tank Conditions					Organic Loading (lb BOD/lb MLSS/day) (kg BOD/kg MLSS/d)
			pH	Temp (°C)	MLSS (mg/L)	Dissolved Oxygen (mg/L)	Sludge Settleability (percent)	
6/12/76	102,000 (465)	0.80	7.9	11.0	1,040	7.4	14	0.38
7/12/76	476,000 (2171)	1.17	7.3	10.0	1,010	6.6	11	0.62
8/12/76	473,000 (2157)	1.25	7.4	10.0	1,630	1.7	17	0.50
9/12/76	475,000 (2166)	1.16	7.3	8.0	1,860	7.4	22	0.45
10/12/76	538,000 (2453)	1.14	7.5	8.0	870	6.3	9	1.03
Average	413,000 (1883)	1.09	7.5	9.5	1,300	5.9	15	0.60

TABLE 16. WASTEWATER TREATMENT SYSTEM PERFORMANCE - PLANT 3
BACTERIOLOGICAL CHARACTERISTICS OF WASTE STREAMS

Sampling Date	Stream	Fecal Coliform Count (per 100 mL)	Salmonella (presence/absence)
6/12/76	Secondary Effluent	240,000	Present
7/12/76	Secondary Effluent	300,000	Present
	Raw Sludge	-	Present
	Digested Sludge	-	Present
8/12/76	Secondary Effluent	159,000	Present
9/12/76	Secondary Effluent	400,000	Present
	Raw Sludge	-	Present
	Digested Sludge	-	Present
10/12/76	Secondary Effluent	310,000	Present
	Raw Sludge	-	Present
	Digested Sludge	-	Present
Average	Secondary Effluent	270,000*	-

* Geometric Mean

6 RESULTS OF PHASE III - PILOT SCALE FIELD INVESTIGATIONS

Phase III of the investigative program involved six weeks of one-site pilot plant operation of two of the selected poultry processing plants, Plant 1 and Plant 2. The pilot scale studies entailed three separate investigations:

- (i) optimization of disinfection processes under winter conditions at Plant 2.
- (ii) evaluation of optimized disinfection processes under summer conditions at Plant 2.
- (iii) evaluation of optimized disinfection processes under summer conditions at Plant 1.

Tracer studies of the pilot plant mixing regimes were undertaken subsequent to definition of the optimum disinfectant conditions.

The results of each part of Phase III of the study are discussed in the following sections.

The disinfection results for the pilot plant runs at conditions selected as optimum are summarized in Table 50 for chlorine and Table 51 for ozone. These summary tables provide a direct comparison of the results of the Phase III program.

6.1 Optimization of Disinfection Processes

As the laboratory investigations in Phase I were carried out on secondary effluent from Plant 1 and the pilot scale optimization process was done at Plant 2, a slightly wider range of disinfectant conditions were assessed during the initial pilot plant runs than originally proposed. The conditions evaluated were as follows for ozone and chlorine:

<u>Chlorination Conditions</u>		<u>Ozonation Conditions</u>	
Applied Dosage (mg/L)	Contact Time (minutes)	Applied Dosage (mg/L)	Contact Time (minutes)
3	45	20	15, 30, 60
5	15, 30, 45	30	15, 30, 60
10	15, 30, 45	40	15, 30, 60
15	15, 30, 45	50	30

These conditions covered the range predicted by the laboratory investigations for control of salmonella contamination in the treated effluent from Plant 1.

The results of the initial ten screening runs under winter conditions at Plant 2 are shown in Table 17 for chlorine and Table 18 for ozone. The disinfection efficiencies at each condition, in terms of percent reduction of the microbiological parameters, are summarized in Table 19 for chlorine and Table 20 for ozone. Salmonella were found in all but one of the secondary effluent samples. The secondary effluent feed during these screening runs, as shown in Table 21, contained high suspended solids and total BOD concentrations and low ammonia concentrations. The effluent chlorine demand was relatively high and the majority of the residual was present as free available chlorine.

Chlorination at 10 mg/L and 45 minutes contact time, and at all contact times at a dosage of 15 mg/L resulted in greater than three log (99.9 percent) reductions in fecal coliform counts. Reduction in standard plate counts ranged from 94.7 to 99.8 percent. Despite reduction of fecal coliform counts to approximately 20 per 100 mL, salmonella were isolated from the effluent after chlorination at 15 mg/L applied dosage and 30 minutes contact time. However, salmonella were not detected after applying 3 mg/L available chlorine at 45 minutes contact time.

Chlorination and ozonation at the higher dosages resulted in high disinfection efficiencies. Reductions in the order of three logs (99.9 percent) in the fecal coliform counts were attained in most cases. Standard plate count reductions were normally in excess of 90 percent. However, control of salmonella in the pilot plant effluents was not directly related to disinfection conditions. Salmonella were occasionally isolated after relatively high chlorine and ozone dosages and long contact times (e.g. 15 mg/L available chlorine and 45 minutes contact; 40 mg/L ozone and 60 minutes contact), whereas in other runs less severe conditions resulted in reductions in salmonella content to the level of detection. The limitations of the qualitative test protocol for assessing the efficiency of disinfection are evident. The chemical and quantitative bacteriological quality of the secondary effluent affects the efficiency of the disinfection process.

TABLE 17. PILOT SCALE OPTIMIZATION OF CHLORINATION CONDITIONS, INITIAL SCREENING RUNS IN WINTER - PLANT 2

Date	Secondary Effluent				Disinfection Conditions				Pilot Plant Effluent			
	Fecal			Salmo-nella (present/absent)	Applied Dosage (mg/L)	Contact Time (min)	Residual (mg/L)		Standard Plate Count (per mL)	Coliform Count (per 100 mL)	ATP Content (ng/ml)	Salmo-nella (present/absent)
	Standard Plate Count (per mL)	Coliform Count (per 100 mL)	ATP Content (ng/mL)				Total	Free				
17/3/77	43,000	65,000	98	Present	3	45	0.55	0.49	2,400	380	30	Absent
9/2/77	174,000	260,000	105	Present	5	15	0.20	0.15	560,000	23,000	110	Present
10/2/77	72,000	103,000	13	Absent	5	30	0.80	0.70	13,500	18,000	21	Absent
15/2/77	38,600	209,000	97	Present	5	45	0.78	0.74	1,250	2,800	27	Absent
3/3/77	80,000	440,000	51	Present	10	15	1.75	1.65	2,300	500	13	Absent
16/2/77	45,000	320,000	63	Present	10	30	1.5	1.4	2,360	3,700	22	Absent
18/2/77	68,000	65,000	31	Present	10	45	0.70	0.66	560	20	8.2	Absent
8/3/77	113,000	870,000	98	Present	15	15	2.4	2.2	6,000	250	12	Absent
7/3/77	148,000	190,000	130	Present	15	30	2.0	1.3	920	22	8.4	Present
4/3/77	111,000	159,000	56	Present	15	45	3.8	3.6	180	28	1.3	Absent

TABLE 18. PILOT SCALE EVALUATION OF OZONATION CONDITIONS, INITIAL SCREENING RUNS IN WINTER - PLANT 2

Date	Secondary Effluent				Disinfection Conditions				Pilot Plant Effluent			
	Standard Plate Count (per mL)	Fecal Coliform Count (per 100 mL)	ATP Content (ng/mL)	Salmonella (present/absent)	Applied Dosage (mg/L)	Contact Time (min)	Residual (mg/L)	Total	Standard Plate Count (per mL)	Fecal Coliform Count (per 100 mL)	ATP Content (ng/mL)	Salmonella (present/absent)
9/2/77	174,000	260,000	105	Present	20	15	0.12		35,100	2,350	145	Present
10/2/77	72,000	103,000	13	Absent	20	30	0.10		2,480	1,040	2.5	Absent
15/2/77	38,600	209,000	97	Present	20	60	0.08		21,400	42,000	75	Absent
16/2/77	45,000	320,000	63	Present	30	15	0.15		28,800	133,000	46	Absent
18/2/77	68,000	65,000	31	Present	30	30	0.03		61,000	64,000	28	Present
3/3/77	80,000	440,000	51	Present	30	60	0.02		68,000	1,800	43	Present
8/3/77	113,000	870,000	98	Present	40	15	0.04		5,600	900	15	Absent
16/3/77	76,000	190,000	150	Present	40	30	0.14		460	140	6.8	Absent
4/3/77	111,000	159,000	56	Present	40	60	<0.01		66,000	128,000	56	Present
7/3/77	148,000	190,000	130	Present	50	30	<0.01		1,500	290	9.8	Absent

TABLE 19. SUMMARY OF CHLORINATION EFFICIENCY IN INITIAL SCREENING RUNS IN WINTER - PLANT 2

Applied Chlorine Dosage (mg/L)	Contact Time (minutes)	Disinfection Efficiency (% reduction)					Salmonella (present/absent)
		Chlorine Residual (mg/L)		Standard Plate Count	Fecal Coliform Count	ATP Content	
		Total	Free				
3	45	0.55	0.49	94.4	99.4	69.4	Absent
5	15	0.20	0.15	-	91.2	-	Present
5	30	0.80	0.70	81.3	82.5	-	Absent
5	45	0.78	0.74	96.8	98.7	77.8	Absent
10	15	1.8	1.7	97.1	99.9	74.5	Absent
10	30	1.5	1.4	94.8	98.8	65.1	Absent
10	45	0.70	0.66	99.2	>99.9	73.5	Absent
15	15	2.4	2.2	94.7	>99.9	87.8	Absent
15	30	2.0	1.3	99.4	>99.9	93.5	Present
15	45	3.8	3.6	99.8	>99.9	97.7	Absent

TABLE 20. SUMMARY OF OZONATION EFFICIENCY IN INITIAL SCREENING RUNS IN WINTER - PLANT 2

Applied Ozone Dosage (mg/L)	Contact Time (minutes)	Ozone Residual (mg/L)	Disinfection Efficiency (% reduction)			Salmonella (present/absent)
			Standard Plate Count	Fecal Coliform Count	ATP Content	
20	15	0.12	79.8	99.1	-	Present
20	30	0.10	96.6	99.9	80.0	Absent
20	60	0.08	44.6	79.9	22.7	Absent
30	15	0.15	36.0	58.4	27.0	Absent
30	30	0.03	1.5	10.8	9.7	Present
30	60	0.02	15.0	99.6	15.7	Present
40	15	0.04	95.0	99.0	84.7	Absent
40	30	0.14	99.4	>99.9	95.5	Absent
40	60	<0.01	40.5	19.5	-	Present
50	30	<0.01	99.0	99.8	92.5	Absent

TABLE 21. SECONDARY EFFLUENT QUALITY DURING INITIAL SCREENING RUNS IN WINTER - PLANT 2

Date	Temp (°C)	pH	BOD (mg/L)		Suspended Solids (mg/L)	Hexane Extractable Oils (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Ammonia Nitrogen (mg/L)
			Total	Soluble				
9/2/77	3.0	7.2	30	<5	51	2	12.2	<0.1
10/2/77	2.5	6.8	52	10	113	3	19.7	0.1
15/2/77	5.0	7.0	49	8	65	1	15.7	<0.1
16/2/77	4.5	6.5	40	8	47	3	11.1	<0.1
18/2/77	3.0	6.3	28	<5	36	1	5.2	0.2
3/3/77	4.0	6.8	56	20	76	1	9.8	<0.1
4/3/77	6.0	7.2	45	6	42	2	3.9	<0.1
7/3/77	3.5	6.3	48	5	81	1	7.9	0.2
8/3/77	4.5	6.6	55	12	63	2	9.1	0.1
16/3/77	9.5	6.4	58	7	62	1	6.4	<0.1
17/3/77	8.0	6.4	60	17	66	1	16.8	<0.1

Based on the observed trends in the laboratory and initial pilot plant screening runs, six of the initial runs for each disinfectant were selected for duplicate runs under winter conditions at Plant 2. The conditions selected were:

Chlorination Conditions		Ozonation Conditions	
Applied Dosage (mg/L)	Contact Time (minutes)	Applied Dosage (mg/L)	Contact Time (minutes)
5	15, 30, 45	20	60
10	15, 30, 45	30	15, 30, 60
		40	15, 60

A wider range of conditions was selected for ozonation because the initial screening tests indicated that ozone effectiveness was much more dependent on the influent quality.

The results of the six duplicate runs with each disinfectant under winter conditions at Plant 2 are shown in Table 22 for chlorine and Table 23 for ozone. The disinfection efficiencies at each condition, in terms of percent reduction in the bacterial parameters, are summarized in Table 24 for chlorine and Table 25 for ozone. *Salmonella* were detected in all but one of secondary effluent samples. Secondary effluent quality during the duplicate runs, as summarized in Table 26, was similar to the quality of pilot plant feed during the initial screening runs.

Salmonella were detected in the effluent after 15 minutes contact and an applied dosage of 5 mg/L available chlorine, despite a reduction of fecal coliform count in excess of three logs (99.9 percent). *Salmonella* were not detected in the pilot plant effluent in any of the other runs.

Ozonation appeared to be more effective in the duplicate runs than during the initial screening tests. All conditions more severe than 30 mg/L and 15 minutes contact time resulted in greater than three log reductions in fecal coliform counts. However, *salmonella* were isolated from the pilot plant effluent at the two least severe conditions and at the most severe condition, 40 mg/L ozone at a contact time of 60 minutes.

TABLE 22. PILOT SCALE EVALUATION OF CHLORINATION CONDITIONS, DUPLICATE RUNS IN WINTER - PLANT 2

Date	Secondary Effluent				Disinfection Conditions				Pilot Plant Effluent			
	Standard Plate Count (per mL)	Fecal Coliform Count (per 100 mL)	ATP Content (g/mL)	Salmo-nella (present/absent)	Applied Dosage (mg/L)	Contact Time (min)	Residual (mg/L)		Standard Plate Count (per mL)	Fecal Coliform Count (per 100 mL)	ATP Content (g/mL)	Salmo-nella (present/absent)
							Total	Free				
9/3/77	78,000	670,000	87	Present	5	15	1.3	1.1	1,340	100	11	Present
10/3/77	198,000	370,000	33	Absent	5	30	0.83	0.76	7,500	650	14	Absent
11/3/77	245,000	610,000	210	Present	5	45	1.07	0.85	14,800	6,100	74	Absent
14/3/77	265,000	190,000	210	Present	10	15	0.97	0.88	10,300	100	43	Absent
15/3/77	61,000	250,000	88	Present	10	30	1.1	0.80	830	30	6.8	Absent
16/3/77	76,000	190,000	150	Present	10	45	1.3	0.91	590	190	6.6	Absent

TABLE 23. PILOT SCALE EVALUATION OF OZONATION CONDITIONS, DUPLICATE RUNS WINTER - PLANT 2

Secondary Effluent				Disinfection Conditions				Pilot Plant Effluent			
Date	Fecal			Salmo- nella (present/ absent)	Applied Dosage (mg/L)	Contact Time (min)	Residual (mg/L) Total	Fecal			Salmo- nella (present/ absent)
	Standard Plate Count (per mL)	Coliform Count (per 100 mL)	ATP Content (ng/mL)					Standard Plate Count (per mL)	Coliform Count (per 100 mL)	ATP Content (ng/mL)	
9/3/77	78,000	670,000	87	Present	30	60	<0.01	13,300	270	91	Absent
10/3/77	198,000	370,000	33	Absent	30	30	0.04	9,200	320	22	Absent
11/3/77	245,000	610,000	210	Present	30	15	0.02	16,900	1,000	84	Present
14/3/77	265,000	190,000	210	Present	20	60	<0.01	96,000	140,000	91	Present
15/3/77	61,000	250,000	88	Present	40	60	0.03	3,400	140	20	Present
17/3/77	43,000	65,000	98	Present	40	15	0.72	610	30	38	Absent

TABLE 24. SUMMARY OF CHLORINATION EFFICIENCY IN DUPLICATE RUNS IN WINTER - PLANT 2

Applied Chlorine Dosage (mg/L)	Contact Time (minutes)	Chlorine Residual (mg/L)		Disinfection Efficiency (% reduction)			Salmonella (present/absent)
		Total	Free	Standard Plate Count	Fecal Coliform Count	ATP Content	
5	15	1.3	1.1	98.3	>99.9	87.4	Present
5	30	0.83	0.76	96.2	99.8	57.6	Absent
5	45	1.07	0.85	94.0	99.0	64.8	Absent
10	15	0.97	0.88	96.1	>99.9	79.5	Absent
10	30	1.1	0.80	98.6	>99.9	92.3	Absent
10	45	1.3	0.91	99.2	99.9	95.6	Absent

TABLE 25. SUMMARY OF OZONATION EFFICIENCY IN DUPLICATE RUNS IN WINTER - PLANT 2

Applied Ozone Dosage (mg/L)	Contact Time (minutes)	Ozone Residual (mg/L)	Disinfection Efficiency (% reduction)			Salmonella (present/absent)
			Standard Plate Count	Fecal Coliform Count	ATP Content	
20	60	<0.01	26.3	63.8	56.7	Present
30	15	0.02	93.1	99.8	60.0	Present
30	30	0.04	95.4	>99.9	33.3	Absent
30	60	<0.01	82.9	>99.9	-	Absent
40	15	0.72	98.6	>99.9	61.2	Absent
40	60	0.03	94.4	>99.9	77.3	Present

TABLE 26. SECONDARY EFFLUENT QUALITY DURING DUPLICATE RUNS IN WINTER - PLANT 2

Date	Temp (°C)	pH	BOD (mg/L)		Suspended Solids (mg/L)	Hexane Extractable Oils (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Ammonia Nitrogen (mg/L)
			Total	Soluble				
9/3/77	7.0	6.1	45	8	52	0.8	10.3	<0.1
10/3/77	9.0	6.5	48	14	52	1.2	9.1	<0.1
11/3/77	10.0	6.6	85	11	156	0.9	14.3	0.1
14/3/77	9.0	6.5	70	<5	148	0.9	15.7	<0.1
15/3/77	9.5	6.5	39	<5	58	0.6	9.8	0.2
16/3/77	9.5	6.4	58	7	62	1.0	6.4	<0.1
17/3/77	8.0	6.4	60	17	66	1.3	16.8	<0.1

Selection of the least severe disinfection conditions required to ensure control of salmonella in the secondary effluent under all circumstances is not possible under these conditions of varying influent quality. Therefore, disinfection conditions which would result in control of salmonella under the majority of circumstances were selected as optimum, based on these data. The conditions selected were for five replicate runs as follows:

Chlorination:	Applied Dosage - 10 mg/L
	Contact Time - 45 minutes
Ozonation:	Applied Dosage - 30 mg/L
	Contact Time - 60 minutes

In both cases, less severe disinfection conditions had successfully reduced the salmonella content of the effluent to the limit of detection. However, more severe conditions had been unsuccessful for control of salmonella in some cases. It was anticipated that the selected conditions would result in adequate control of salmonella under the majority of circumstances.

The results of pilot plant operation at the conditions selected as optimum are shown in Table 27 for chlorine and Table 28 for ozone. Five runs were done for each disinfectant on five consecutive poultry plant operating days. The disinfectant efficiencies for each run are summarized in Table 29 (chlorine) and Table 30 (ozone). Secondary effluent quality during this period, as shown in Table 31, was consistent with that observed during the previous runs under winter conditions. Again, all but one of the secondary effluent samples showed the presence of salmonella. During the two-month period of winter investigations at Plant 2, salmonella were detected in 87 percent of the secondary effluent samples.

Salmonella were not detected in any of the chlorination pilot plant effluent samples during the five runs at conditions selected as optimum. Fecal coliform count reductions in the order of three logs, 99.8 to 99.9 percent, were attained. Greater than one-log reductions in standard plate counts, 95.6 to 99.4 percent, and ATP content, 90.6 to 91.8 percent, resulted. For all seven runs carried out at an applied chlorine dosage of 10 mg/L and 45 minutes contact time at Plant 2 under winter conditions, the average removal efficiencies were:

TABLE 27. PILOT SCALE EVALUATION OF 'OPTIMUM' CHLORINATION CONDITIONS IN WINTER - PLANT 2

Date	Secondary Effluent				Disinfection Conditions				Pilot Plant Effluent			
	Fecal		Salmo- nella (present/ absent)	ATP Content (ng/mL)	Applied Dosage (mg/L)	Contact Time (min)	Residual (mg/L)		Standard Plate Count (per mL)	Coliform Count (per 100 mL)	ATP Content (ng/ml)	Salmo- nella (present/ absent)
	Standard Plate Count (per mL)	Coliform Count (per 100 mL)					Total	Free				
22/3/77	68,000	97,000	Present	100	10	45	1.0	0.90	780	190	8.7	Absent
23/3/77	23,400	27,000	Absent	68	10	45	1.3	1.3	1,040	64	6.0	Absent
24/3/77	32,300	78,000	Present	100	10	45	1.3	1.2	560	110	8.7	Absent
25/3/77	90,000	90,000	Present	65	10	45	1.8	1.4	570	50	5.3	Absent
28/3/77	60,000	240,000	Present	90	10	45	1.6	1.4	1,400	110	8.5	Absent

TABLE 28. PILOT SCALE EVALUATION OF "OPTIMUM" OZONATION CONDITIONS IN WINTER - PLANT 2

Date	Secondary Effluent			Disinfection Conditions			Pilot Plant Effluent		
	Standard Plate Count (per mL)	Fecal Coliform Count (per 100 mL)	Salmo-nella ATP Content (present/absent) (ng/mL)	Applied Dosage (mg/L)	Contact Time (min)	Residual (mg/L) Total	Standard Plate Count (per mL)	Fecal Coliform Count (per 100 mL)	Salmo-nella ATP Content (present/absent) (ng/mL)
22/3/33	68,000	97,000	100 Present	30	60	0.04	12,700	350	41 Absent
23/3/77	23,400	27,000	68 Absent	30	60	0.04	13,800	380	53 Absent
24/3/77	32,300	78,000	100 Present	30	60	0.06	5,400	120	42 Absent
25/3/78	90,000	90,000	65 Present	30	60	0.40	13,500	200	42 Absent
28/3/77	60,000	240,000	90 Present	30	60	0.03	105,000	460	80 Absent

TABLE 29. SUMMARY OF CHLORINATION EFFICIENCY AT "OPTIMUM" CONDITIONS IN WINTER - PLANT 2

Applied Chlorine Dosage (mg/L)	Contact Time (minutes)	Chlorine Residual (mg/L)		Disinfection Efficiency (% reduction)			Salmonella (present/absent)
		Total	Free	Standard Plate Count	Fecal Coliform Count	ATP Content	
10	45	1.0	0.90	98.9	99.8	91.3	Absent
10	45	1.3	1.3	95.6	99.8	91.2	Absent
10	45	1.3	1.2	99.2	99.9	91.3	Absent
10	45	1.8	1.4	99.4	>99.9	91.8	Absent
10	45	1.6	1.4	97.7	>99.9	90.6	Absent

TABLE 30. SUMMARY OF OZONATION EFFICIENCY AT "OPTIMUM" CONDITIONS IN WINTER - PLANT 2

Applied Ozone Dosage (mg/L)	Contact Time (minutes)	Ozone Residual (mg/L)	Disinfection Efficiency (% reduction)			Salmonella (present/absent)
			Standard Plate Count	Fecal Coliform Count	ATP Content	
30	60	0.04	81.3	99.6	59.0	Absent
30	60	0.04	41.0	98.6	22.1	Absent
30	60	0.06	83.3	99.8	58.0	Absent
30	60	0.40	85.0	99.8	35.4	Absent
30	60	0.03	-	99.8	11.1	Absent

TABLE 31. SECONDARY EFFLUENT QUALITY DURING "OPTIMUM" RUNS IN WINTER - PLANT 2

Date	Temp (°C)	pH	BOD (mg/L)		Suspended Solids (mg/L)	Hexane Extractable Oils (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Ammonia Nitrogen (mg/L)
			Total	Soluble				
22/3/77	4.0	6.6	50	43	60	1.0	12.9	<0.1
23/3/77	4.0	6.8	60	14	50	2.0	12.3	<0.1
24/3/77	2.5	7.1	50	6	90	<1.0	12.3	<0.1
25/3/77	3.0	7.1	33	11	60	1.0	12.8	<0.1
28/3/77	3.5	7.2	48	13	88	1.5	12.3	<0.1

	Fecal Coliform Count	Standard Plate Count	ATP Content
Efficiency (percent reduction)	99.9	98.5	89.3

Salmonella were not detected in any of the seven chlorinated effluent samples.

Ozonation was successful for controlling salmonella discharges during the five final runs at optimum conditions. Salmonella content of the effluents was reduced to the limit of detection in all cases. However, the relative efficiency in terms of the other bacterial parameters was somewhat lower than comparable results with chlorine. Maximum reduction of fecal coliform count was less than three logs, 99.8 percent. Reductions of standard plate counts and ATP content were significantly less. Average disinfection efficiencies in terms of these three parameters for all seven runs at optimum ozonation conditions were:

	Fecal Coliform Count	Standard Plate Count	ATP Content
Efficiency (percent reduction)	99.6	55.5	28.8

Overall, salmonella were not detected in 85.7 percent of the secondary effluent samples disinfected with 30 mg/L ozone at 60 minutes contact time.

During the laboratory scale Phase I studies, there appeared to be some correlation between the ATP content of the secondary effluent and the disinfection conditions. No direct correlation between ATP and disinfection conditions was evident in the pilot plant results. A trend toward increasing ATP content with increased standard plate count and

fecal coliform count is evident although no statistically significant correlation could be drawn from the data available. More detailed investigations would be required to define the significance of ATP in disinfection wastes.

Operating conditions for the biological treatment system at Plant 2 in winter are summarized in Table 32. In general, operation of the treatment system was comparable to that observed during the Phase II survey. However, in extreme cold, the efficiency of the secondary clarifier was severely reduced by freezing problems. As the objective of the winter operation was optimization of disinfection conditions, the pilot plants were operated only under secondary effluent conditions considered representative of normal operation.

Low ammonia concentrations, less than 1 mg/L, in the secondary effluent were observed during the winter program despite influent kjeldahl nitrogen concentrations of 60 to 95 mg/L. High dissolved oxygen and mixed liquor concentrations in the aeration basin indicated that efficient nitrification could be occurring despite the low temperatures. Limited analysis of the secondary effluent indicated concentrations in excess of 20 mg/L of nitrogen in the nitrate and nitrite form. Regular analysis of the secondary effluent for nitrate and nitrite were added to the summer sampling program.

Severe cold during the winter of 1977 created freezing of the water lines at Plant 2. As a result, the tertiary clarifier effluent could not be filtered or chlorinated before discharge. Tertiary effluent represented the final effluent from the plant during this period. Effluent quality is summarized in Table 33.

Without chlorination, the final effluent contained high bacterial concentrations. The pH in the tertiary clarifier was maintained in the neutral range by balanced addition of lime and alum. Reductions in bacterial concentration in the tertiary system were probably the result of coagulation and sedimentation of biological solids. The tertiary effluent solids were principally chemical floc, indicated by the lower total BOD content of the final effluent relative to the secondary effluent. Salmonella were detected in only 56 percent of the final effluent samples compared to 87 percent of the secondary effluent samples.

TABLE 32. BIOLOGICAL TREATMENT OPERATING CONDITIONS IN WINTER - PLANT 2

Date	Influent Characteristics							Mixed Liquor Characteristics					
	Flow (lgpd)	pH	Temp (°C)	BOD (mg/L)		Suspended Solids (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Ether Extract- able Oil (mg/L)	pH	Temp (°C)	MLSS (mg/L)	Dissol- ved Oxygen (mg/L)	Sludge Settle- ability (percent)
				Total	Soluble								
9/2/77	81,400	7.0	15.0						7.2	1.5	6,360	6.8	35
10/2/77	102,500	6.5	17.0	733	197	177			6.8	2.0	6,820	5.2	35
15/2/77	86,800	6.3	14.0						6.8	1.0		6.0	40
16/2/77	76,000	6.7	13.5	393	105	372			7.2	0.0	6,840	8.4	35
18/2/77									6.2	1.0	7,160		39
3/3/77	150,700	7.3	16.0	597	215	299			6.4	4.0	6,750	5.7	30
4/3/77		7.5	8.0	303	207	68			7.2	5.0	6,570	8.2	38
7/3/77	101,000	6.4	14.5	360	120	284			6.6	3.0	6,520	7.6	35
8/3/77	86,700	6.5	14.0	620	233	466			6.5	3.5	6,120	6.6	35
9/3/77	77,500	6.8	17.0	750	285	376			6.2	7.0	6,140	6.0	31
10/3/77	87,000	6.5	17.0	750	220	290			6.2	9.0	6,060	1.8	33
11/3/77	87,300	7.0	17.0	615	175	346	60.5	51	6.6	9.0	7,210	1.4	37
14/3/77	82,700	6.8	16.0			406	73.1	78	6.5	9.0	6,280		35
15/3/77	73,500	6.2	16.0			305	87.9	144	6.6	9.5	6,110	2.8	36
16/3/77	80,400	6.8	15.0						6.5	9.0	6,340	4.2	34
17/3/77	82,000	6.8	17.0						6.4	7.5	5,590		34
22/3/77	87,000	7.0	14.5	770	240	300	94.1	125	6.6	6.0	6,620		38
23/3/77									6.6	4.0	6,350		38
24/3/77	92,000	6.9	17.5						7.1	2.5	6,760	4.2	40
25/3/77	89,000	7.0	15.5	650	250	345	77.1	172	7.0	3.0	5,640	3.7	38
28/3/77	90,000	7.0	17.0	730					6.9	3.5	6,160	4.5	37

TABLE 33. FINAL EFFLUENT QUALITY IN WINTER - PLANT 2

Date	Bacteriological Quality				Chemical Quality			
	Standard Plate Count (per mL)	Fecal Coliform Count (per 100 mL)	ATP Content (ng/mL)	Salmonella (present/absent)	pH	Temp (°C)	Total Soluble	Suspended Solids (mg/L)
9/2/77	174,000	560,000	105	Present	7.7	3.5	27	108
10/2/77	72,000	103,000	13	Absent	6.9	3.0	14	22
15/2/77					7.7	4.5	25	61
16/2/77					7.8	5.0	9	23
18/2/77	70,000	117,000	4.6	Absent	6.8	3.0	<5	23
3/3/77	29,000	120,000	6.8	Present	7.3	4.0	24	43
7/3/77	102,000	66,000	17	Absent	6.5	4.5	11	31
8/3/77	99,000	580,000	53	Absent	6.7	8.0	24	27
9/3/77	71,000	430,000	53	Present	6.5	8.0	32	46
10/3/77	183,000	280,000	38	Present	6.8	9.5	42	62
11/3/77	153,000	420,000	66	Present	7.9	10.0	38	78
14/3/77	285,000	170,000	98	Absent	6.9	10.0	46	99
15/3/77	213,000	280,000	62	Absent	6.9	10.5	27	82
16/3/77	93,000	150,000	170	Present	6.9	12.0	29	66
17/3/77	89,000	122,000	24	Present	7.0	9.5	46	64
22/3/77	54,000	43,000	27	Present	7.0	6.5	24	48
23/3/77	57,000	20,000	19	Absent	7.2	4.5	22	38
24/3/77	46,000	23,000	32	Present	7.5	4.0	18	50
25/3/77	73,000	48,000	45	Present	7.2	4.5	30	20
28/3/77	118,000	89,000	47	Absent	7.2	8.0	28	62

6.2 Evaluation of Optimized Disinfection Processes under Summer Conditions at Plant 2

The disinfection conditions selected as optimum were further assessed under summer conditions at Plant 2. Pilot plant operating conditions during the five summer runs were the same as during the final five replicate runs under winter conditions. The optimum disinfection conditions were:

Chlorination:	Applied Dosage - 10 mg/L
	Contact Time - 45 minutes
Ozonation:	Applied Dosage - 30 mg/L
	Contact Time - 60 minutes

As an objective of the program was to assess the ability of chlorine and ozone to control salmonella over a range of secondary effluent conditions, no attempt was made to select a particular effluent quality for the summer evaluation of the disinfectants.

The results of the pilot plant operation are shown in Table 34 for chlorine and Table 35 for ozone. The disinfection efficiencies, in terms of percent reduction of bacterial contamination, are summarized in Table 36 (chlorine) and Table 37 (ozone).

Secondary effluent quality during the five summer runs given in Table 38 was, in general, poorer than during the winter study. In particular, higher effluent ammonia and suspended solids concentrations were evident. Low aeration tank pH, 4.6 to 5.7, in conjunction with lower dissolved oxygen and mixed liquor suspended solids concentrations in the aeration tank appeared to severely inhibit the nitrification observed during the winter pilot plant studies. As a result of higher effluent ammonia concentrations in the effluent, the total chlorine residual consisted primarily of combined chlorine.

Despite the changes in secondary effluent quality, disinfection efficiency resulting from chlorination under summer conditions was comparable to that attained under winter conditions. Average reductions in the microbiological parameters were:

TABLE 34. PILOT SCALE EVALUATION OF "OPTIMUM" CHLORINATION CONDITIONS IN SUMMER - PLANT 2

Date	Secondary Effluent				Disinfection Conditions				Pilot Plant Effluent			
	Fecal				Applied Dosage (mg/L)	Contact Time (min)	Cl Residual (mg/L)		Standard Plate Count (per mL)	Coliform Count (per 100 mL)	ATP Content (ng/ml)	Salmo-nella (present/absent)
	Standard Plate Count (per mL)	Coliform Count (per 100 mL)	ATP Content (ng/mL)	Salmo-nella (present/absent)			Total	Free				
30/5/77	2,300,000	560,000	135	Present	10	45	0.79	<0.05	6,700	400	24	Absent
31/5/77	390,000	117,000	24.5	Present	10	45	2.25	1.32	2,700	190	2.8	Absent
1/6/77	220,000	71,000	60	Present	10	45	2.28	0.67	1,600	100	11.6	Absent
2/6/77	390,000	350,000	70	Present	10	45	1.68	0.40	5,100	1,120	17	Absent
3/6/77	69,000	110,000	62	Absent	10	45	2.62	1.08	1,300	110	7.1	Absent

TABLE 35. PILOT SCALE EVALUATION OF "OPTIMUM" OZONATION CONDITIONS IN SUMMER - PLANT 2

Date	Secondary Effluent				Disinfection Conditions			Pilot Plant Effluent		
	Fecal		Salmo-		Applied Dosage (mg/L)	Contact Time (min)	Residual (mg/L)	Fecal		Salmo-
	Standard Plate Count (per mL)	Coliform Count (per 100 mL)	ATP Content (ng/mL)	nella (present/absent)				Standard Plant Count (per mL)	Coliform Count (per 100 mL)	nella ATP Content (ng/mL) (present/absent)
30/5/77	2,300,000	560,000	135	Present	30	60	<0.01	14,700	1,800	19.5 Absent
31/5/77	390,000	117,000	24.5	Present	30	60	0.04	3,700	190	5.9 Absent
1/6/77	220,000	71,000	60	Present	30	60	<0.01	360,000	4,900	72 Present
2/6/77	390,000	350,000	70	Present	30	60	0.02	110,000	370	25.5 Absent
3/6/77	69,000	110,000	62	Absent	30	60	<0.01	3,600	130	20 Absent

TABLE 36. SUMMARY OF CHLORINATION EFFICIENCY AT "OPTIMUM" CONDITIONS IN SUMMER - PLANT 2

Applied Chlorine Dosage (mg/L)	Contact Time (minutes)	Disinfection Efficiency (% reduction)					Salmonella (present/absent)
		Chlorine Residual (mg/L)		Standard Plate Count	Fecal Coliform Count	ATP Content	
		Total	Free				
10	45	0.79	<0.05	99.7	>99.9	82.2	Absent
10	45	2.25	1.32	99.3	99.8	88.6	Absent
10	45	2.28	0.67	99.3	99.9	80.7	Absent
10	45	1.68	0.40	98.7	99.7	75.7	Absent
10	45	2.62	1.08	98.1	99.9	88.5	Absent

TABLE 37. SUMMARY OF OZONATION EFFICIENCY AT "OPTIMUM" CONDITIONS IN SUMMER - PLANT 2

Applied Ozone Dosage (mg/L)	Contact Time (minutes)	Ozone Residual (mg/L)	Disinfection Efficiency (% reduction)			Salmonella (present/absent)
			Standard Plate Count	Fecal Coliform Count	ATP Content	
30	60	<0.01	99.4	99.7	85.6	Absent
30	60	0.04	99.0	99.8	75.9	Absent
30	60	<0.01	-	93.1	-	Present
30	60	0.02	71.8	99.9	63.6	Absent
30	60	<0.01	94.8	99.8	67.7	Absent

TABLE 38. SECONDARY EFFLUENT QUALITY DURING "OPTIMUM" RUNS IN SUMMER - PLANT 2

Date	Temp (°C)	pH	BOD (mg/L)		Suspended Solids (mg/L)	Hexane Extractable Oils (mg/L)		Total Kjeldahl Nitrogen (mg/L)	Ammonia Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	Nitrite Nitrogen (mg/L)
			Total	Soluble							
30/5/77	14.0	6.1	71	9	400	4.2	40.9	35.1	-	-	-
31/5/77	14.5	5.7	43	12	155	2.0	26.3	19.8	30.0	0.2	0.2
1/6/77	16.5	5.7	41	13	365	<1.0	40.9	27.9	38.0	0.1	0.1
2/6/77	17.0	6.0	53	15	100	2.1	32.5	18.9	25.0	0.3	0.3
3/6/77	15.0	6.0	30	8	85	2.7	26.9	18.5	17.0	0.2	0.2

	Fecal Coliform Count	Standard Plate Count	ATP Content
Efficiency (percent reduction)	99.8	99.0	33.1

Actual effluent standard plate and fecal coliform counts were higher after chlorination in the summer study than during the winter because influent concentrations were also higher.

Four of the five secondary effluent samples during the summer study contained salmonella, comparable to the results of the winter survey. Salmonella were not detected in any of the pilot plant effluent samples after chlorination at 10 mg/L applied dosage and 45 minutes contact time under summer conditions at Plant 2.

Ozonation efficiency was also similar under winter and summer conditions. As with chlorine, the actual bacterial counts in the pilot plant effluents were higher during the summer but percent reductions were comparable. The efficiency of ozonation was as follows:

	Fecal Coliform Count	Standard Plate Count	ATP Content
Efficiency (percent reduction)	98.5	73.0	58.6

Salmonella were not detected in four of the five ozone pilot plant effluents. In the run in which salmonella were detected, the lowest overall disinfection efficiency of the five runs, in terms of the other bacteriological parameters, was attained.

This sample contained a relatively high concentration of suspended solids, biological floc carryover from the secondary clarifier.

Operating conditions for the biological treatment system during the summer sampling program are summarized in Table 39. Aeration tank pH was low during this period. The higher ambient temperatures resulted in lower aeration tank dissolved oxygen concentrations. Settled sludge volumes approached 50 percent despite lower mixed liquor suspended solids concentrations in the aeration basin. Poor sludge settleability, combined with mechanical problems with the clarifier scraper mechanism, resulted in high secondary effluent suspended solids concentrations during the five-day period.

The chemical and bacteriological quality of selected waste streams at the treatment plant are summarized in Tables 40 and 41, respectively. Tertiary clarifier effluent was filtered and chlorinated prior to discharge during the summer. However, due to the operating mode of the chlorination system during this period, representative values of disinfectant residual could not be obtained. The chlorine feed pump discharged continuously to the effluent line. Tertiary effluent pumping was controlled by on-off level controllers. Therefore, the instantaneous chlorine dosage was dependent on the tertiary effluent pumping cycle. Calculated dosage based on the average daily raw waste flow was approximately 15 mg/L available chlorine.

The screened process waste contained higher concentrations of organic contaminants during the summer period. However, low effluent soluble BOD indicated adequate biological stabilization of organics in the aeration basin. High effluent ammonia concentrations indicated that biological nitrification had been severely inhibited by the operating conditions.

High suspended solids carryover from the tertiary clarifier was observed during the summer program. These solids were primarily inorganic floc from the chemical precipitation of phosphorus. The tertiary effluent contained relatively high concentrations of total phosphorus.

Tertiary effluent was maintained at near neutral pH, reducing the effectiveness of the system for reduction of bacterial concentrations. Four of the five tertiary effluent samples contained salmonella. Standard plate counts and fecal coliform counts were relatively high.

TABLE 39. SUMMARY OF TREATMENT PLANT PERFORMANCE IN SUMMER - PLANT 2

Sampling Date	Stream	pH	Temp (°C)	BOD (mg/L)		Suspended Solids (mg/L)	Hexane Extractable Oils (mg/L)		Total Kjeldahl Nitrogen (mg/L)	Ammonia Nitrogen (mg/L)	Total Phosphorus (mg/L)
				Total	Soluble						
30/5/77	Screened Waste	6.9	24.0	976	180	420	262		87.3	25.1	9.6
	Tertiary Effluent	6.3	14.0	29	6	215	-		23.3	21.8	17.0
	Screened Waste	7.8	22.0	553	230	390	177		79.8	15.3	9.6
31/5/77	Tertiary Effluent	6.3	14.5	34	13	170	-		-	-	15.0
	Chlorinated Effluent	6.5	15.0	-	-	-	-		34.7	22.1	-
	Screened Waste	7.0	22.0	613	195	175	88		79.5	15.9	11.1
1/6/77	Tertiary Effluent	4.3	16.5	15	14	70	-		47.4	38.9	9.6
	Screened Waste	6.3	23.0	1,180	275	600	282		45.6	23.0	15.2
	Tertiary Effluent	9.8	17.0	9	7	85	-		-	-	13.9
2/6/77	Chlorinated Effluent	9.4	17.0	-	-	-	-		54.9	24.1	-
	Screened Waste	6.6	22.0	800	243	445	255		47.6	36.1	12.4
	Tertiary Effluent	6.8	15.5	11	5	70	-		-	-	13.5
3/6/77	Chlorinated Effluent	6.9	16.0	-	-	-	-		22.4	17.9	-

TABLE 40. BACTERIOLOGICAL QUALITY OF EFFLUENT STREAMS IN SUMMER - PLANT 2

Date	Stream	Standard Plate Count (per mL)	Fecal Coliform Count (per 100 mL)	ATP Content (ng/mL)	Salmonella (present/absent)
30/5/77	Tertiary Effluent	620,000	100,000	19.0	Present
	Chlorinated Effluent	140	<10	3.3	Absent
31/5/77	Tertiary Effluent	370,000	82,000	12.7	Present
	Chlorinated Effluent	9,900	170	3.5	Absent
1/6/77	Tertiary Effluent	TNTC	<1,000	0.1	Absent
2/6/77	Tertiary Effluent	1,300,000	85,000	27.5	Present
	Chlorinated Effluent	5,100	1,200	17.0	Absent
3/6/77	Tertiary Effluent	250,000	85,000	25.0	Present
	Chlorinated Effluent	7,700	116	3.3	Absent

TABLE 41. BIOLOGICAL TREATMENT SYSTEM OPERATING CONDITIONS IN SUMMER - PLANT 2

Date	Flow (l/gpd) (m ³ /d)	pH	Temp (°C)	MLSS (mg/L)	Dissolved Oxygen (mg/L)	Sludge Settleability (percent)
30/5/77	90,000 (410)	4.6	14.0	4,690	4.5	50
31/5/77	82,000 (374)	5.2	14.5	4,380	5.0	50
1/6/77	93,500 (426)	5.7	17.0	4,600	3.2	49
2/6/77	88,000 (401)	5.7	17.0	4,640	1.8	46
3/6/77	79,000 (360)	5.6	15.0	4,880	2.4	51

Full scale chlorination was relatively effective for bacterial control. Reductions as great as three logs (99.9 percent) were attained in both standard plate counts and fecal coliform counts. Salmonella were not detected in any of the chlorinated effluent samples. Due to the operating mode of the chlorination system during this period, the measured efficiency of disinfection is dependent on the time during the pumping cycle that the sample is obtained. Extremely high chlorine concentrations can be present at the start of the tertiary effluent pumping cycle.

6.3 Evaluation of Optimized Disinfection Processes under Summer Conditions at Plant 1

The mechanical and operational problems with the biological waste treatment facilities at Plant 1 which had caused difficulties during the winter were still in evidence during the summer. One of the aeration tanks was out of service due to mechanical problems with the aerator. All process wastes were treated in the single remaining biological reactor. The organic load on the system resulted in sludge settleability problems and high secondary effluent suspended solids concentrations.

The second aeration tank was returned to service on the fourth day of pilot plant operation. Secondary effluent quality improved significantly after the addition to the system of biomass stored in the second aeration basin. However, anaerobic odours were obvious in the area of the treatment plant upon start-up of the aerator in the second basin. Secondary effluent was extremely dark in colour, during the final two pilot plant runs despite the improvement in quality. The anaerobic characteristics of the effluent resulted in increased disinfectant demand.

The disinfectants had been effective under poor effluent conditions at Plant 2. The efficiency under bulking sludge conditions at Plant 1 provides an indication of the range of effluent quality over which chlorine and ozone can be successfully applied.

The results of the pilot plant operation at Plant 1 are shown in Table 42 for chlorine and Table 43 for ozone. Summaries of the disinfectant efficiencies of chlorine and ozone are given in Tables 44 and 45 respectively. The secondary effluent exhibited a high chlorine demand particularly during the period of high effluent suspended solids. Total

TABLE 42. PILOT SCALE EVALUATION OF "OPTIMUM" CHLORINATION EFFICIENCY IN SUMMER - PLANT 1

Date	Secondary Effluent			Disinfection Conditions				Pilot Plant Effluent				
	Standard Plate Count (per mL)	Fecal Coliform Count (per 100 mL)	ATP Content (ng/mL)	Salmo-nella (present/absent)	Applied Dosage (mg/L)	Contact Time (min)	Cl Residual (mg/L)		Standard Plate Count (per mL)	Fecal Coliform Count (per 100 mL)	ATP Content (ng/ml)	Salmo-nella (present/absent)
							Total	Free				
13/6/77	2,100,000	120,000	360	Present	10	45	0.75	<0.05	250,000	2,500	525	Present
14/6/77	2,600,000	180,000	345	Present	10	45	0.44	<0.05	500,000	26,000	350	Present
15/6/77	850,000	820,000	785	Present	10	45	1.08	0.43	148,000	17,000	180	Present
16/6/77	41,000	63,000	15.8	Present	10	45	1.82	0.25	41,000	2,400	70	Present
20/6/77	390,000	140,000	39	Present	10	45	1.70	0.37	77,000	2,300	47	Present

TABLE 43. PILOT SCALE EVALUATION OF "OPTIMUM" OZONATION EFFICIENCY IN SUMMER - PLANT 1

Date	Secondary Effluent				Disinfection Conditions				Pilot Plant Effluent			
	Fecal		Salmo-		Applied Dosage (mg/L)	Contact Time (min)	Residual (mg/L) Total	Standard Plate Count (per mL)	Fecal		Salmo-	
	Standard Plate Count (per mL)	Coliform Count (per 100 mL)	ATP Content (ng/mL)	nella (present/absent)					Coliform Count (per 100 mL)	ATP Content (ng/mL)	nella (present/absent)	
13/6/77	2,100,000	120,000	360	Present	30	60	0.01	4,000,000	3,900	167.5	Present	
14/6/77	2,600,000	180,000	345	Present	30	60	0.01	700,000	57,000	420	Present	
15/6/77	850,000	820,000	785	Present	30	60	0.01	750,000	13,000	220	Present	
16/6/77	41,000	63,000	15.8	Present	30	60	0.07	71,000	1,000	1.7	Present	
20/6/77	390,000	140,000	39	Present	30	60	0.04	6,800	500	1.4	Absent	89

TABLE 44. SUMMARY OF CHLORINATION EFFICIENCY AT "OPTIMUM" CONDITIONS IN SUMMER - PLANT 2

Applied Chlorine Dosage (mg/L)	Contact Time (minutes)	Disinfection Efficiency (% reduction)				Salmonella (present/absent)
		Chlorine Residual (mg/L)		Standard Plate Count	Fecal Coliform Count	ATP Content
		Total	Free			
10	45	0.75	<0.05	88.1	97.9	-
						Present
10	45	0.44	<0.05	80.8	85.6	-
						Present
10	45	1.08	0.43	82.6	97.9	77.1
						Present
10	45	1.82	0.25	-	96.2	-
						Present
10	45	1.70	0.37	80.2	98.4	-
						Present

TABLE 45. SUMMARY OF OZONATION EFFICIENCY AT "OPTIMUM" CONDITIONS IN SUMMER - PLANT 1

Applied Ozone Dosage (mg/L)	Contact Time (minutes)	Ozone Residual (mg/L)	Disinfection Efficiency (% reduction)			Salmonella (present/absent)
			Standard Plate Count	Fecal Coliform Count	ATP Content	
30	60	0.01	-	96.8	53.5	Present
30	60	0.01	73.1	68.3	-	Present
30	60	0.01	11.7	98.4	72.0	Present
30	60	0.07	-	98.4	89.2	Present
30	60	0.04	98.3	99.6	96.4	Absent

chlorine residual concentrations were higher on the final two days of operation; however, free residual concentrations after chlorination were low.

The quality of the secondary effluent during the five-day study is summarized in Table 46. The impact of the poor settling filamentous biomass on effluent quality during the initial three runs is obvious from the results. The high solids and organic content of the waste drastically reduced the efficiency of both disinfectants. Influent bacterial counts to the pilot plants were extremely high due to the presence of the active biological solids. The disinfectant demand of the waste reduced the concentration available for active disinfection. Chlorination resulted in reductions of 85.6 to 97.9 percent in the fecal coliform counts and 80.8 and 88.1 percent in the standard plate counts. Reductions after ozonation were 68.3 to 98.4 percent in fecal coliform counts. In two cases, ozonation produced negligible reductions in standard plate counts.

The quality of the secondary effluent improved significantly for the final two pilot plant runs. However, the efficiency of the chlorination process did not show any marked improvement. Ozonation efficiency did improve, particularly in the final run.

Average efficiencies for the alternative disinfectants for the five runs under summer conditions at Plant 1 were as follows:

	Fecal Coliform Count	Standard Plate Count	ATP Content
Chlorine Efficiency (percent reduction)	95.2	66.3	15.4
Ozone Efficiency (percent reduction)	92.3	36.6	62.2

Salmonella were isolated from all five secondary effluent samples at Plant 1. Pilot scale chlorination of the secondary effluent did not result in adequate control of the salmonella discharges.

TABLE 46. SECONDARY EFFLUENT QUALITY DURING "OPTIMUM" RUNS IN SUMMER - PLANT 1

Date	Temp (°C)	pH	BOD (mg/L)		Suspended Solids (mg/L)	Hexane Extractable Oils (mg/L)		Total Kjeldahl Nitrogen (mg/L)	Ammonia Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	Nitrite Nitrogen (mg/L)
			Total	Soluble							
13/6/77	19.0	6.6	555	<5	1,440	5.8	-	-	3.8	-	-
14/6/77	20.5	7.2	560	6	1,460	3.5	-	-	3.3	-	-
15/6/77	21.0	7.7	270	6	940	2.9	30.3	-	5.3	-	-
16/6/77	23.0	7.8	9	8	9	2.8	7.9	-	6.3	<1.0	<0.1
20/6/77	21.0	7.3	48	18	44	<1.0	16.2	-	11.7	<1.0	<0.1

Salmonella were detected in all five samples after chlorination at an applied dosage of 10 mg/L and 45 minutes contact time. Ozonation was more successful than chlorination, reducing salmonella to the level of detection in the final pilot plant run at an applied dosage of 30 mg/L and 60 minutes contact time.

Operating conditions for the biological treatment system at Plant 1 are summarized in Table 47. Filamentous bacteria were evident in the operational aeration tank and resulted in poor sludge settling characteristics. This problem was also observed at Plant 1 during the Phase II survey. The return sludge chlorination system installed to control the growth of filamentous organisms was out of service during the summer period. Low dissolved oxygen concentrations were also evident due to the organic overloading of the single operational aeration basin.

The chemical and bacteriological characteristics of the screened process waste, polishing lagoon effluent and chlorinated effluent are summarized in Tables 48 and 49, respectively. The results for the pilot plant runs at conditions selected as optimum are summarized in Table 50 for chlorine and Table 51 for ozone.

Screened process waste quality was consistent with previous samplings. The lagoon effluent contained higher suspended solids and total BOD concentrations due to the proliferation of algae under summer conditions. Chlorination of the lagoon effluent at approximately 12 mg/L available chlorine resulted in low residual disinfectant concentrations due to the organic content of the stream. Most of the residual was present in combined form. Bacterial reductions resulting from chlorination of the lagoon effluent were insignificant. The lagoon, however, significantly reduced the bacterial content of the secondary effluent, especially the fecal coliform count. The disinfection action is probably a result of ultra-violet radiation and bacterial predators in the lagoons.

Salmonella were isolated in three of the five lagoon effluent samples. Salmonella were also present in three of the five chlorinated effluent samples.

TABLE 47. SUMMARY OF TREATMENT PLANT PERFORMANCE IN SUMMER - PLANT 1

Date	Stream	pH	Temp (°C)	Hexane Extract-			Suspended Solids (mg/L)	BOD Total (mg/L)	Soluble (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Ammonia Nitrogen (mg/L)	Total Phosphorus (mg/L)	Chlorine Residual (mg/L)			
				Temp (°C)	Soluble (mg/L)	Total Kjeldahl Nitrogen (mg/L)							Ammonia Nitrogen (mg/L)	Total Phosphorus (mg/L)	Total	Free
13/6/77	Screened Waste	6.8	28.0	790	288	415	106	72.8	36.1	11.8	-	-	-	-		
	Lagoon Effluent	6.9	22.0	30	17	60	-	-	-	3.8	-	-	-	-		
	Chlorinated Effluent	6.9	22.0	-	-	-	-	9.0	6.6	-	0.53	<0.05	-	-		
14/6/77	Screened Waste	7.6	26.0	1,120	217	680	28	58.2	26.5	10.6	-	-	-	-		
	Lagoon Effluent	7.2	21.0	79	<5	70	-	-	-	6.4	-	-	-	-		
	Chlorinated Effluent	7.1	20.5	-	-	-	-	10.1	9.8	-	0.42	0.20	-	-		
15/6/77	Screened Waste	7.6	28.0	400	130	320	92	33.0	26.7	9.6	-	-	-	-		
	Lagoon Effluent	7.0	21.5	48	17	35	-	-	-	6.7	-	-	-	-		
	Chlorinated Effluent	7.1	21.5	-	-	-	-	10.1	7.8	-	0.62	0.15	-	-		
16/6/77	Screened Waste	7.9	28.0	670	216	470	238	85.1	28.1	10.7	-	-	-	-		
	Lagoon Effluent	7.0	20.0	25	13	30	-	-	-	6.0	-	-	-	-		
	Chlorinated Effluent	7.2	21.0	-	-	-	-	12.3	12.1	-	0.94	0.20	-	-		

TABLE 4 7. (CONT'D)

Date	Stream	pH	Temp (°C)	BOD (mg/L)		Suspended Solids (mg/L)	Hexane Extract- able Oils (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Ammonia Nitrogen (mg/L)	Total Phosphorus (mg/L)	Chlorine Residual (mg/L)	
				Total	Soluble						Total	Free
20/6/77	Screened Waste	7.3	27.0	350	125	216	84	75.0	31.2	35.4	-	-
	Lagoon Effluent	7.0	21.0	35	12	41	-	-	-	11.5	-	-
	Chlorinated Effluent	7.0	21.0	-	-	-	-	18.6	14.4	-	0.73	<0.05

TABLE 48. BACTERIOLOGICAL QUALITY OF EFFLUENT STREAMS IN SUMMER - PLANT 1

Date	Stream	Standard Plate Count (per mL)	Fecal Coliform Count (per 100 mL)	ATP Content (ng/mL)	Salmonella (present/absent)
13/6/77	Lagoon Effluent	83,000	1,000	64	Present
	Chlorinated Effluent	350,000	570	68	Absent
14/6/77	Lagoon Effluent	85,000	2,300	78	Present
	Chlorinated Effluent	34,000	3,000	60	Absent
15/6/77	Lagoon Effluent	76,000	4,700	84	Absent
	Chlorinated Effluent	220,000	1,700	44	Present
16/6/77	Lagoon Effluent	34,000	500	31	Present
	Chlorinated Effluent	34,000	2,400	70	Present
20/6/77	Lagoon Effluent	172,000	200	48	Absent
	Chlorinated Effluent	940,000	TNTC	22	Present

TABLE 49. BIOLOGICAL TREATMENT SYSTEM OPERATING CONDITIONS IN SUMMER - PLANT 1

Date	Flow (lmgd) (m ³ /d)	pH	Temp (°C)	MLSS (mg/L)	Dissolved Oxygen (mg/L)	Sludge Settleability (percent)
13/6/77	0.5 (2280)	6.4	18.0	2,860	0.4	90
14/6/77	0.5 (2280)	7.5	19.0	2,790	0.1	92
15/6/77	0.5 (2280)	7.5	20.0	2,330	0.1	85
16/6/77	0.5 (2280)	7.5	21.0	2,900	0.2	74
20/6/77	0.5 (2280)	7.4	20.0	2,900	0.3	76

TABLE 50. SUMMARY OF CHLORINATION EFFICIENCY AT "OPTIMUM" CONDITIONS

Conditions: Applied Dosage 10 mg/L
Contact Time 45 minutes

Plant No.	Season	Average Residual (mg/L)		Mean Effluent Concentration*					Average Removal Efficiency ** (percent)			Percent of Time Salmonella Not Detected in Effluent
		Total	Free	Standard Plate Count (per mL)		Fecal Coliform Count (per 100 mL)		ATP Content (ng/ML)	Standard Plate Count	Fecal Coliform Count		
				ATP	Content	Standard Plate Count	Fecal Coliform Count					
2	Winter	1.3	1.1	740	85	7.3	98.5	99.3	89.3	100		
2	Summer	1.9	0.7	2,860	250	9.9	99.0	99.8	83.1	100		
1	Summer	1.2	0.2	142,500	5,700	161.0	66.3	95.2	15.4	0		

* Geometric Mean

** In cases where effluent concentration is greater than influent, removal efficiency is taken as 0% for averaging purposes.

TABLE 51. SUMMARY OF OZONATION EFFICIENCY AT "OPTIMUM" CONDITIONS

Conditions: Applied Dosage 30 mg/L
Contact Time 65 minutes

Plant No.	Season	Average Residual (mg/L)	Mean Effluent Concentration*			Average Removal Efficiency ** (percent)			Percent of Time Salmonella Not Detected in
			Standard Plate Count (per mL)	Fecal Coliform Count (per 100 mL)	ATP Content (ng/mL)	Standard Plate Count	Fecal Coliform Count	ATP	
2	Winter	0.09	19,850	350	53	55.5	99.6	28.8	85.7
2	Summer	0.02	28,950	600	21	73.0	98.5	58.6	80.0
1	Summer	0.03	252,000	4,300	33	36.6	92.3	62.2	20.0

* Geometric Mean

** In cases where effluent concentration is greater than influent, removal efficiency is taken as 0% for averaging purposes.

6.4 Pilot Plant Mixing Conditions

The mixing regimes in the pilot scale disinfection systems are defined by tracer studies using Rhodamine B at the operating conditions defined as optimum based on the bacteriological results. The response of the systems to a pulse input of dye is shown in Figure 8 for the chlorine contact chamber and Figure 9 for the ozone contact chambers. The concentration time function for the tracer in the exit stream of the contact systems is shown in terms of dimensionless coordinates C and θ . The mixing regimes were defined according to the dispersion model. The statistical methods for evaluation of the mixing regime by the dispersion model are outlined in detail in Levenspiel (1962).

The intensity of dispersion in the reaction vessel is characterized by the reactor dispersion number $D/\mu L$. This parameter varies from zero for a plug flow reactor to infinity for a backmix flow reactor. Characterization of flows between the two ideal regimes of plug and backmix flow is normally as follows:

$\frac{D}{\mu L}$	=	0	Plug flow
$\frac{D}{\mu L}$	=	0.002	Small amount of dispersion
$\frac{D}{\mu L}$	=	0.025	Intermediate amount of dispersion
$\frac{D}{\mu L}$	=	0.2	Large amount of dispersion
$\frac{D}{\mu L}$	=	∞	Backmix flow (high dispersion)

The reactor dispersion number for the chlorine contact system was approximately 1.4, indicating conditions approaching backmix flow. Disinfection by chlorination is known to be most effective in plug flow reactors. The pilot scale chlorination results probably represent the least favourable conditions for the experimental dosage, contact times and feed qualities. The optimum conditions for chlorination, 10 mg/L and 45 minutes contact time, represent conservative estimates of the disinfection requirements for good quality secondary effluent from

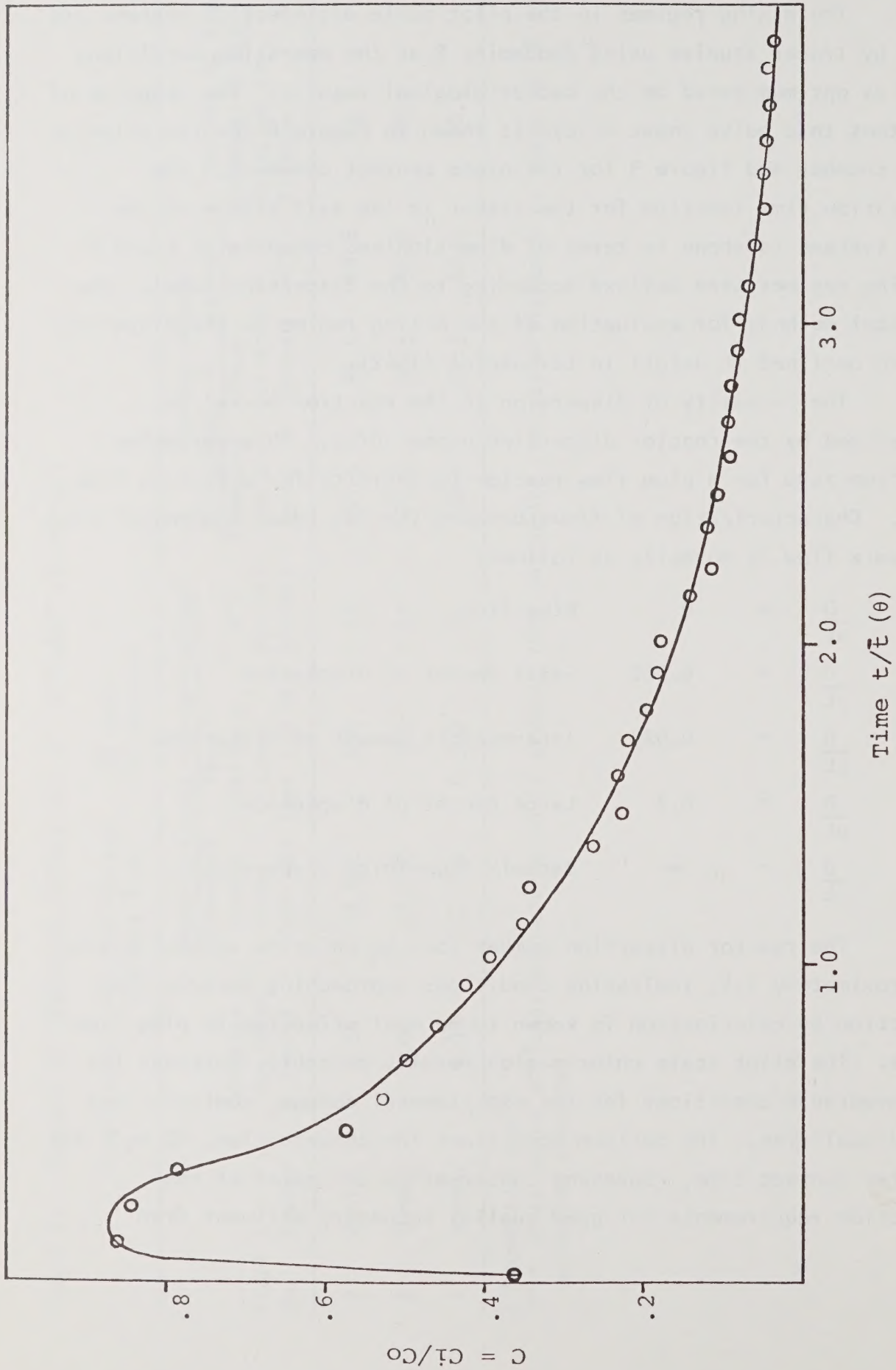


FIGURE 8. RESIDENCE TIME DISTRIBUTION IN PILOT SCALE CHLORINATION CHAMBER

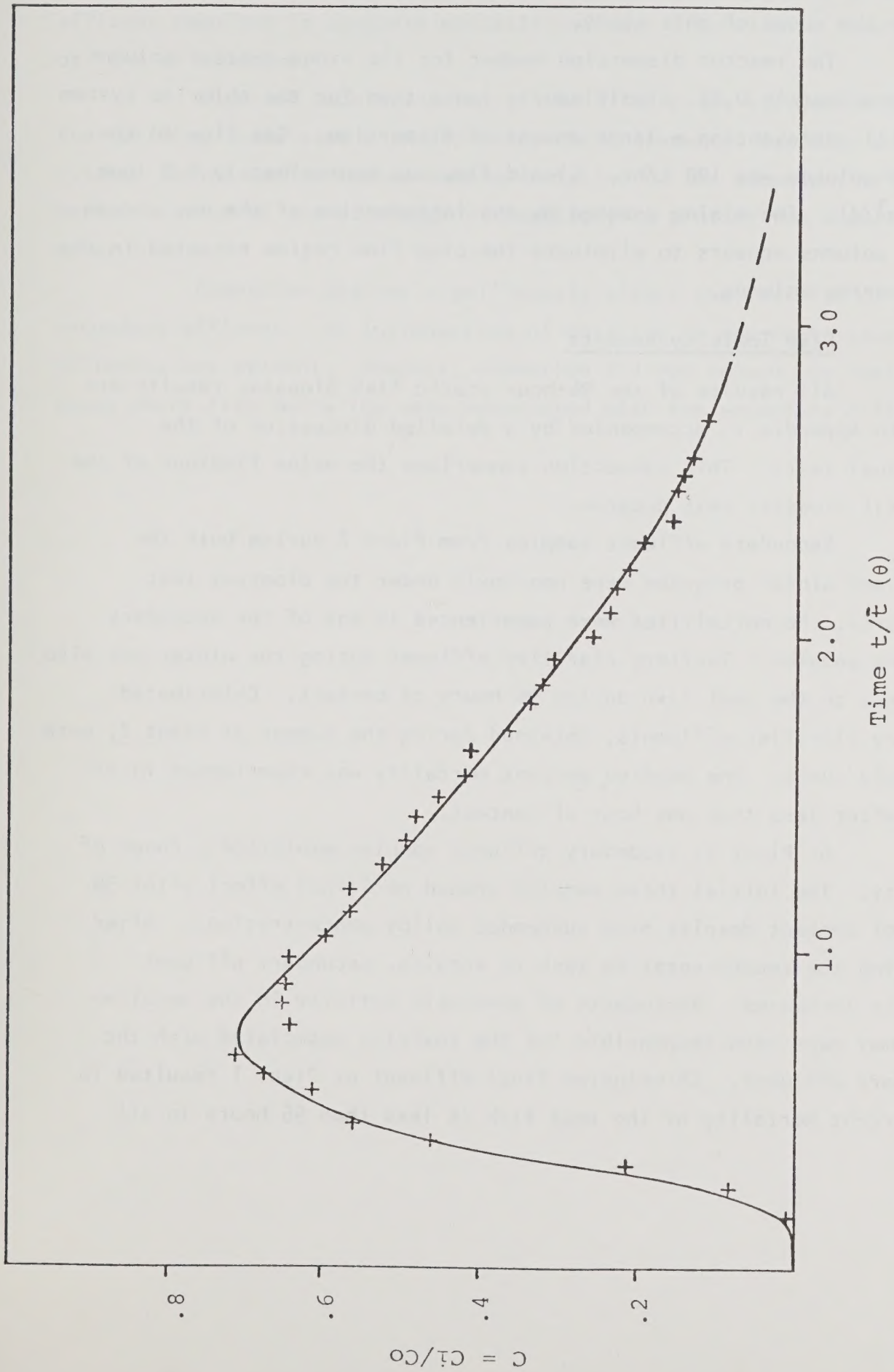


FIGURE 9. RESIDENCE TIME DISTRIBUTION IN PILOT SCALE OZONE CONTACT SYSTEM

poultry processing plants. To attain a plug flow mixing regime would require an infinite number of mixed tanks in series or a reactor design outside the scope of this study.

The reactor dispersion number for the ozone contact columns was approximately 0.22, significantly lower than for the chlorine system but still representing a large amount of dispersion. Gas flow to the contact columns was 100 L/hr. Liquid flow was approximately 0.5 lpm (2280 m³/d). The mixing created by the introduction of the gas stream to the columns appears to eliminate the plug flow regime expected in the long, narrow columns.

6.5 Fish Toxicity Results

All results of the 96-hour static fish bioassay results are given in Appendix I, accompanied by a detailed discussion of the individual tests. This subsection summarizes the major findings of the Phase III bioassay test program.

Secondary effluent samples from Plant 2 during both the summer and winter programs were non-toxic under the bioassay test procedures. No mortalities were experienced in any of the secondary effluent samples. Tertiary clarifier effluent during the winter was also non-toxic to the test fish during 96 hours of contact. Chlorinated tertiary clarifier effluents, obtained during the summer at Plant 2, were extremely toxic. One hundred percent mortality was experienced in all cases after less than one hour of contact.

At Plant 1, secondary effluent samples exhibited a range of toxicity. The initial three samples showed no lethal effect after 96 hours of contact despite high suspended solids concentrations. After returning the second aeration tank to service, secondary effluent toxicity increased. Byproducts of anaerobic activity in the aeration basin may have been responsible for the toxicity associated with the secondary effluent. Chlorinated final effluent at Plant 1 resulted in 100 percent mortality of the test fish in less than 96 hours in all cases.

Pilot scale chlorination of the secondary effluent introduced a significant degree of toxicity. In most cases, chlorinated pilot plant effluent resulted in complete mortality of test fish with in four hours or less of exposure.

Chemical dechlorination of the pilot plant effluent eliminated the toxicity associated with chlorine. No incremental toxicity was evident in the dechlorinated samples relative to the secondary effluent. Dechlorination of the discharge is necessary to protect the receiving water biota.

Ozonation did not significantly affect the toxicity of the secondary effluent. No introduction of toxicity to non-toxic secondary effluents was evident. However, ozonation did not reduce the toxicity in cases where fish mortality were associated with the secondary effluent.

ECONOMIC IMPLICATIONS

The pilot scale investigations indicated that the control of salmonella discharges from treated poultry processing plant effluents is dependent on maintaining good quality effluent from the secondary treatment facility. Under adequate treatment plant operation, the following disinfectant conditions were found to be adequate:

Chlorination: Applied Dosage - 10 mg/L
Contact Time - 45 minutes

Ozonation: Applied Dosage - 30 mg/L
Contact Time - 60 minutes

These conditions are the basis for the economic evaluation of disinfectant alternatives.

Up-to-date cost data for both processes were obtained from local chemical and equipment suppliers. Background data was also obtained from the literature for ozone generation costs. The economic evaluation of alternatives is based on disinfecting 1.0 lmgd (4,560 m³/d) of biologically-treated poultry processing plant effluent.

8.1 Chlorination/Dechlorination

Fish toxicity results indicated that dechlorination prior to discharge is necessary to produce an environmentally-acceptable effluent. Therefore, chemical dechlorination facilities using sulphur dioxide are included in the economic evaluation of chlorine. No contact chamber is specified as the dechlorination reaction is virtually instantaneous given adequate mixing with the chlorinated effluent stream. Dechlorination can therefore be carried out in the discharge pipe. The outfall should be designed to provide a high degree of turbulence and re-aeration of the discharge to eliminate any oxygen deficiency caused by the addition of sulphur dioxide to the effluent stream.

Based on chlorine residuals experienced during the pilot plant studies, sulphur dioxide dosages of approximately 5 mg/L are adequate to eliminate the residual disinfectant concentrations. Chlorination costs are based on gaseous chlorine. The following 1977 costs have been developed for the chlorination-dechlorination system based on estimates from chemical and equipment suppliers.

(a) Capital Costs:

Baffled Contact Chamber, volume 5,000 ft ³ (142 m ³)	\$33,000
Chlorine Dosage System	\$ 5,000
Sulphur Dioxide Dosage System	<u>\$ 5,000</u>
Total Capital Cost	\$43,000

(b) Operating Costs

Chlorine - 100 lb/day @ \$0.20/lb (45 kg/d) (\$0.44/kg)	\$20.00/day
Sulphur Dioxide - 50 lb/day @ \$0.33/lb (23 kg/d) (\$0.73/kg)	<u>\$16.50/day</u>
Chemical Costs	\$36.50/day
	\$0.037/1,000 lgal (\$0.008/m ³)
Amortization of Capital at 15% annually	<u>\$17.67/day</u>
Total Operating Cost	\$54.17/day
	\$0.054/1,000 lgal (\$0.01/m ³)

Therefore, capital cost of chlorination-dechlorination facilities for a one lmgd (4,560 m³/d) plant would be approximately \$43,000. Operating costs, including amortization of capital, are estimated at \$54.17 per day, equivalent to \$0.054/1,000 lgal (\$0.01/m³).

7.2 Ozonation

Review of the literature and contact with suppliers of ozone generation equipment indicated that production of ozone from dry air is most economical unless a supply of pure oxygen is available for other purposes. Therefore, the capital cost of ozone generation includes an air preparation unit to produce air at -40°C for the generator. Two alternate contact systems could be provided for ozonation: columns similar to the system used for the pilot scale work, or a covered, baffled tank equipped with gas diffusers similar in design to a diffused air aeration basin. Capital costs of the two alternate contact systems are comparable.

Operating costs for the system are primarily the result of power requirements, estimated at 10 kwh per pound of ozone. The following 1977 costs for ozonation have been developed based on estimates from chemical and equipment suppliers.

(a) Capital Costs:

Air Preparation Unit	\$ 70,000
Ozone Generator, up to maximum 300 lb (136 kg) O ₃ /day	\$140,000
Contact System (Columns or Basin) Total volume 6,700 ft ³ (190 m ³) equipped with diffusers, etc.	<u>\$ 50,000</u>
Total Capital Cost	\$260,000

(b) Operating Costs:

Power Requirements - 3,000 kwh/day - \$0.02/kwh (11,000 Mj/day - \$0.006/Mj)	<u>\$ 60.00/day</u>
Total Power Cost	\$ 60.00/day
	\$0.06/1,000 lgal (\$0.01/m ³)
Amortization of Capital at 15% annually	<u>\$106.85/day</u>
Total Operating Cost	\$166.85/day
	\$0.17/1,000 lgal (\$0.04/m ³)

Therefore, capital cost of the ozonation facilities for a 1 lmgd plant would be approximately \$260,000. Operating costs, including amortization of capital, are estimated at \$166.85 per day, equivalent to \$0.17/1,000 lgal (\$0.04/m³).

Direct comparison with costs given in the literature is difficult because many authors do not state operating conditions or chemical dosage and amortization of capital is not always included in operating cost estimates. Further, updating costs based on equipment indices and general inflation factors are not necessarily valid for such specific equipment as ozone generators. Nevertheless, to confirm that cost estimates for ozonation obtained from suppliers were in agreement

with literature values, a brief review of literature information was compiled. Cost data provided by Huibers, McNabney and Halfon (1969), Wynn, Kirk and McNabney (1973), Harris (1974) and Rosen (1974) confirm the cost information provided by suppliers. A summary of the literature cost information is provided in Table 52.

TABLE 52. COST ESTIMATES FOR OZONATION FOUND IN THE LITERATURE

Reference	Capital Cost	Operating Cost	Comments
Huibers, McNabney and Halfon (1969)	\$202,000	\$0.272/1,000 U.S.gal (\$0.07/m ³)	1 mgd (3785 m ³ /d) Secondary Effluent
Wynn, Kirk and McNabney (1973)	\$426,000	\$0.20/1,000 U.S.gal (\$0.05/m ³)	1 mgd Secondary Effluent at 40 mg/L ozone. Comparative chlorine costs cited as \$0.02/1,000 U.S.gal (\$0.005/m ³)
Harris (1974)	\$170,000	-	Ozone Generation Equipment for 1 mgd (4,560 m ³ /d) poultry processing plant system
Rosen (1974)	\$155,000	\$1.07/1,000 U.S.gal (\$0.28/m ³)	Capital cost for 1 mgd (4,560 m ³ /d) operation. Operating cost for 10 mgd (37,850 m ³ /d) at 5 mg/L ozone. Comparative chlorine costs cited as \$0.01/1,000 U.S.gal (\$0.003/m ³)

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REFERENCES

1. Harris, W.C., "Ozone for water: What's the Story?", *Water and Wastes Engineering*, 11, 44, 1974.
2. Huibers, D.T.A., McNabney, R., and Halfon, A., "Ozone Treatment of Secondary Effluents from Wastewater Treatment Plants". Robert A. Taft Wtr. Res. Ctr. Rprt. No. TWRC-4, FWPCA, Washington, D.C. (Apr. 1969).
3. Levenspiel, O., Chemical Reaction Engineering, John Wiley and Sons, Inc. London (1962).
4. Rosen, H.M., "Use of Ozone and Oxygen in Advanced Wastewater Treatment", *Jour. Water Poll. Control Fed.*, 46, 2788, (1974).
5. Standard Methods for the Examination of Water and Wastewater, Thirteenth Edition, American Public Health Association, New York, (1971).
6. Tennant, A.D., Toxopeus, R., Bastien, J.A.P., Beauchamp, M., Vandewint, J., "Salmonella in Poultry Packing Plant Effluents", Technology Development Report EPS-4-OR-75-1, Environmental Protection Service, Ontario Region, Environment Canada, (1975). Reprinted in Report No. EPS 3-WP-76-9.
7. Vanderpost, J.M. and Bell, J.B., "A bacteriological investigation of meat packing plant effluents in the Province of Alberta, with particular emphasis on Salmonella", Technology Development Report EPS 4-NW-75-1, Environmental Protection Service, Northwest Region, Environment Canada, (1975). Reprinted in Report No. EPS 3-WP-76-9.
8. Wynn, C.S., Kirk, B.S., and McNabney, R., "Pilot Plant for Tertiary Treatment of Wastewater with Ozone", U.S. Environmental Protection Agency Technology Report EPA-R2-73-146, (1973).

LIST OF ABBREVIATIONS

Al	Aluminium
ATP	Adenosine triphosphate
Avg	Average
°C	Celsius degrees
$\frac{D}{\mu L}$	Reactor dispersion number
lgal	Imperial gallon
lgpm	Imperial gallons per minute
lgpd	Imperial gallons per day
lgpd/ft ²	Imperial gallons per day per square foot
kwh	Kilowatt-hour
MIG	Million Imperial gallons
Imgd	Million Imperial gallons per day
min.	Minute
MLSS	Mixed liquor suspended solids
mg/L	Milligrams per litre
ng/ml	Nanogram per millilitre
P	Phosphorus
TNTC	Too numerous to count (bacterial concentration)
∞	Infinity

APPENDIX I

FISH TOXICITY RESULTS

APPENDIX I - FISH TOXICITY RESULTS

A. Phase I Results

The results of 96-hour static fish bioassays for the Phase I laboratory study are given in Tables I-1 and I-2 for screening tests 2 and 3, respectively. In screening test 2, there was some toxicity associated with the non-disinfected secondary effluent. Twenty percent mortality of the test fish resulted after 96 hours of contact. Chlorination significantly increased the toxicity of the waste. Mortality was increased to 100 percent after only 24 hours in the effluent treated with 10 mg/L chlorine. The lower chlorine dosage, 5 mg/L, also resulted in some increase in the toxicity of the waste.

Dechlorination with sodium sulphite reduced the toxicity of the chlorinated secondary effluent. Samples of secondary effluent chlorinated at 5 mg/L and dechlorinated with sodium sulphite showed no toxicity to the test fish during the 96-hour test period.

Ozonation of the effluent eliminated any toxicity associated with the waste during the 96-hour static tests.

The secondary effluent for screening test 3 was highly toxic. One hundred percent mortality of the test fish resulted after only eight hours of contact. High ammonia-nitrogen concentration, 16.7 mg/L, was probably responsible for the lethal effect of the waste. None of the treatment methods affected the ultimate toxicity of the waste after 96-hours, although the rate of fish mortality did vary from sample to sample.

B. Treatment Plant Streams - Plant 2

Results for samples obtained under winter operating conditions are given in Tables I-3 to I-11. During this period, the chlorination system was not operational due to freezing problems. Tertiary effluent represented the final effluent from the system. Toxicity results under summer conditions are given in Tables I-12 to I-21. The final effluent during this period was polished by filtration and chlorinated.

Throughout the winter investigations at Plant 2, the tertiary effluent showed no toxicity to fish under the 96-hour static test

conditions. Similarly, the secondary effluents used as feed to the pilot scale disinfection systems during the final optimization runs were non-toxic after 96 hours of contact in all cases.

During the summer runs at Plant 2, the chlorinated final effluent samples were extremely toxic to the test fish. One hundred percent mortality was experienced in all cases after less than one hour of contact. The secondary effluent samples were non-toxic, despite significantly higher ammonia concentrations than evident during the winter sampling program. Secondary effluent used as feed to the pilot scale disinfection system showed no lethal effect on the test fish after 96 hours of contact.

C. Treatment Plant Streams - Plant 1

Toxicity results for treatment plant streams at Plant 1 are given in Tables 1-12 to 1-16. Final effluent was the discharge of the polishing lagoon after chlorination.

Secondary effluent from Plant 1 exhibited a wide range of toxicity. The initial three samples (June 13, 14 and 15) showed no lethal effect after 96 hours despite high suspended solids concentrations. The final two secondary effluent samples (June 16 and 20) exhibited lethal effects varying from 70 percent after 96 hours to complete mortality after four hours of exposure. These last two samples appeared to be of significantly better quality than the initial three samples, notably in terms of suspended solids content. On June 16, the second aeration basin, which had been out of service for six months, was put back on line. Anaerobic odours, most notably hydrogen sulphide, were evident in the area of the basin upon start-up of the aerator. By-products of anaerobic activity in the aeration tank may have been responsible for the increased toxicity of the secondary effluent.

Final effluent samples resulted in complete mortality of the test fish in less than 96 hours, despite relatively low residual chlorine concentrations. In the worst case, none of the test fish survived more than eight hours in the effluent.

D. Phase III Effect of Chlorination

At Plant 2, under winter conditions, chlorination of secondary effluent introduced significant toxicity to the waste stream. In four of

five samples, 100 percent mortality of the test fish resulted after four hours or less of exposure to the pilot plant effluent. In the chlorinated sample of March 25, 1977 (Table I-10), no toxicity was evident within 96 hours. This sample was stored for three days at 4°C prior to analysis. It is probably that the chlorine residual had been reduced to non-toxic levels prior to initiation of the bioassay. It appears that dechlorination by storage could effectively eliminate the additional toxicity associated with chlorination.

Effluent from the pilot scale chlorination system was also highly toxic during the summer program at Plant 2. In four of the five samples treated, one hundred percent mortality in the test fish was observed in less than four hours of exposure. In the fifth sample, 100 percent mortality occurred at between 24 and 48 hours of exposure.

At Plant 1, chlorination of secondary effluent during the initial three days of pilot plant operation resulted in very low disinfectant residuals due to the high organic and suspended solids content of the waste. As a result, the toxicity of these effluents was relatively low. Maximum toxicity was 20 percent after 96 hours of exposure. The final two chlorine pilot plant samples were extremely toxic, producing complete mortality of the test fish in two hours or less. Chlorination resulted in a significant increase in secondary effluent toxicity in these cases.

E. Phase III - Effect of Dechlorination

Chemical dechlorination of the chlorine pilot plant effluent with sodium sulphite eliminated the additional toxicity associated with chlorine.

At Plant 2, under both winter (Tables I-7 to I-11) and summer conditions, (Tables I-12 to I-16) there was no fish mortality after 96 hours of contact with the dechlorinated effluent.

At Plant 1 (Tables I-17 to I-21), dechlorination of the pilot plant effluent reduced the toxicity of the waste to approximately the level exhibited by the secondary effluent.

F. Phase III - Effect of Ozonation

Ozonation of the secondary effluent did not significantly affect the toxicity. In cases where the secondary effluent was non-

toxic, ozonation did not introduce any toxicity. In cases where toxicity was associated with the secondary effluent, no significant improvement was evident.

At Plant 2, under both winter and summer conditions, there was no fish mortality with the ozonated effluents.

At Plant 1, ozonation did not appear to affect the toxicity of the second effluent. No significant reductions in fish mortalities were evident after ozonation of secondary effluents containing toxic constituents.

TABLE 1-3

TEST DATE:	February 11, 1977*	DILUTION WATER:	Dechlorinated Acton Water
PROCEDURE:	Static 96 hour Pass/Fail (Schedule III Food Industry Guidelines)	SAMPLE STORAGE:	Less than 24 hours
FISH CONDITION:	No Pretest Mortality	pH RANGE:	7.9 to 8.1
STOCKING RATIO	Average 2 Litres/Gram	DISSOLVED OXYGEN RANGE:	8.7 to 9.6 mg/L
FISH SPECIES:	Rainbow Trout		

Sample	0	$\frac{1}{4}$	$\frac{1}{2}$	1	2	4	8	12	24	72	96
- percent mortality at time (hours) -											
Control	1.	0	0	0	0	0	0	0	0	0	0
Control	2.	0	0	0	0	0	0	0	0	0	0
Tertiary Effluent Plant 2	1.	0	0	0	0	0	0	0	0	0	0
Tertiary Effluent Plant 2	2.	0	0	0	0	0	0	0	0	0	0

*REMARKS: Received February 10, 1977

TABLE 1-4

TEST DATE:	February 17, 1977*	DILUTION WATER:	Dechlorinated Acton Water
PROCEDURE:	Static 96-hour Pass/Fail (Schedule III Food Industry Guidelines)	SAMPLE STORAGE:	Less than 48 hours
FISH CONDITION:	No Pretest Mortality	pH RANGE:	7.9 to 8.2
STOCKING RATIO:	Average 2 Litres/Gram	DISSOLVED OXYGEN RANGE:	9.4 to 10.2 mg/L
FISH SPECIES:	Rainbow Trout		

Sample	0	$\frac{1}{4}$	$\frac{1}{2}$	1	2	4	8	12	24	72	96
- percent mortality at time (hours) -											
Control	1.	0	0	0	0	0	0	0	0	0	0
Control	2.	0	0	0	0	0	0	0	0	0	0
Tertiary Effluent Plant 2	1.	0	0	0	0	0	0	0	0	0	0
Tertiary Effluent Plant 2	2.	0	0	0	0	0	0	0	0	0	0

*REMARKS: Received February 15, 1977

TABLE 1-5

TEST DATE:	February 17, 1977*	DILUTION WATER:	Dechlorinated Acton Water
PROCEDURE:	Static 96-hour Pass/Fail (Schedule III Food Industry Guidelines)	SAMPLE STORAGE:	Less than 24 hours
FISH CONDITION:	No Pretest Mortality	pH RANGE:	8.0 to 8.2
STOCKING RATIO:	Average 2 Litres/Gram	DISSOLVED OXYGEN RANGE:	9.9 to 10.2 mg/L
FISH SPECIES:	Rainbow Trout		

Sample	0	$\frac{1}{4}$	$\frac{1}{2}$	1	2	4	8	12	24	72	96
- percent mortality at time (hours) -											
Control	1.	0	0	0	0	0	0	0	0	0	0
Control	2.	0	0	0	0	0	0	0	0	0	0
Tertiary Effluent Plant 2	1.	0	0	0	0	0	0	0	0	0	0
Tertiary Effluent Plant 2	2.	0	0	0	0	0	0	0	0	0	0

*REMARKS: Received February 16, 1977

TEST DATE (start):	March 8, 1977	TEST STOCK	No pretest
(received):	March 8, 1977	CONDITION:	mortality
BIOASSAY PROCEDURE:	Static 96-hour	DISSOLVED OXYGEN	
TEST SPECIES:	Rainbow Trout	RATE:	8.1 to 9.6 mg/L
DILUTION WATER:	Dechlorinated Acton Tap Water	pH RANGE:	7.6 to 8.4
STOCKING RATIO:	Average 2 Litres/Gram	TEMPERATURE:	15 ± 1°C

[illegible]

[illegible]

est

[illegible]

- percent mortality at time (hours) -

TABLE 1-12

TEST DATE (start);	May 31, 1977	TEST STOCK	No pretest								
(sampled);	May 30, 1977	CONDITION;	mortality								
BIOASSAY PROCEDURE:	Static 96-hour	DISSOLVED OXYGEN									
TEST SPECIES:	Rainbow Trout	RATE:	9.0 to 10.2 mg/L								
DILUTION WATER:	Dechlorinated Acton	pH RANGE:	6.1 to 8.2								
	Tap Water	TEMPERATURE:	15 ± 1°C								
STOCKING RATIO:	Average 2 Litres/Gram										
Sample	0	$\frac{1}{4}$	$\frac{1}{2}$	1	2	4	8	24	48	72	96
- percent mortality at time (hours) -											
Secondary Effluent											
211-III-1	1.	0	0	0	0	0	0	0	0	0	0
Secondary Effluent											
211-III-1	2.	0	0	0	0	0	0	0	0	0	0
Chlorinated											
211-III-2	1.	0	0	0	0	0	0	90	100	100	100
Chlorinated											
211-III-2	2.	0	0	0	0	0	0	100	100	100	100
Chlorinated-											
Dechlorinated											
211-III-3	1.	0	0	0	0	0	0	0	0	0	0
Chlorinated-											
Dechlorinated											
211-III-3	2.	0	0	0	0	0	0	0	0	0	0
Ozonated											
211-III-4	1.	0	0	0	0	0	0	0	0	0	0
Ozonated											
211-III-4	2.	0	0	0	0	0	0	0	0	0	0
Control	1.	0	0	0	0	0	0	0	0	0	0
Control	2.	0	0	0	0	0	0	0	0	0	0

REMARKS: pH adjusted from about 5.0 with a concentrated solution of sodium hydroxide to between 6.0 and 7.0 (added to all test samples).

TABLE 1-13

TEST DATE (start):	June 1, 1977	TEST STOCK	No pretest
(sampled):	May 31, 1977	CONDITION:	mortality
BIOASSAY PROCEDURE:	Static 96-hour	DISSOLVED OXYGEN	
TEST SPECIES:	Rainbow Trout	RATE:	8.6 to 10.1 mg/L
DILUTION WATER:	Dechlorinated Acton	pH RANGE:	5.9 to 8.1
	Tap Water	TEMPERATURE:	15 ± 1°C
STOCKING RATIO:	Average 2 Litres/Gram		

Sample	0	$\frac{1}{4}$	$\frac{1}{2}$	1	2	4	8	24	48	72	96
- percent mortality at time (hours) -											
Secondary Effluent 211-III-5	1.	0	0	0	0	0	0	0	0	0	0
Secondary Effluent 211-III-5	2.	0	0	0	0	0	0	0	0	0	0
Final Effluent 211-III-6	1.	0	40	100	100	100	100	100	100	100	100
Final Effluent 211-III-6	2.	0	60	100	100	100	100	100	100	100	100
Chlorinated 211-III-7	1.	0	0	0	20	100	100	100	100	100	100
Chlorinated 211-III-7	2.	0	0	10	90	100	100	100	100	100	100
Chlorinated- Dechlorinated 211-III-8	1.	0	0	0	0	0	0	0	0	0	0
Chlorinated- Dechlorinated 211-III-8	2.	0	0	0	0	0	0	0	0	0	0
Ozonated 211-III-9	1.	0	0	0	0	0	0	0	0	0	0
Ozonated 211-III-9	2.	0	0	0	0	0	0	0	0	0	0
Control	1.	0	0	0	0	0	0	0	0	0	0
Control	2.	0	0	0	0	0	0	0	0	0	0

REMARKS: pH adjusted from about 5.0 with a concentrated (100%) solution of sodium hydroxide to between 6.0 and 7.0 (added to all test samples).

TABLE 1-14

TEST DATE (start):	June 2, 1977	TEST STOCK	No pretest								
(sampled):	June 1, 1977	CONDITION:	mortality								
BIOASSAY PROCEDURE:	Static 96-hour	DISSOLVED OXYGEN									
TEST SPECIES:	Rainbow Trout	RATE:	8.2 to 10.0 mg/L								
DILUTION WATER:	Dechlorinated Acton Tap Water	pH RANGE:	5.8 to 8.1								
		TEMPERATURE:	15 ± 1°C								
STOCKING RATIO:	Average 2 Litres/Gram										
Sample	0	$\frac{1}{4}$	$\frac{1}{2}$	1	2	4	8	24	48	72	96
- percent mortality at time (hours) -											
Secondary Effluent											
211-III-10	1.	0	0	0	0	0	0	0	0	0	0
Secondary Effluent											
211-III-11	2.	0	0	0	0	0	0	0	0	0	0
Chlorinated											
211-III-11	1.	0	0	100	100	100	100	100	100	100	100
Chlorinated											
211-III-11	2.	0	0	100	100	100	100	100	100	100	100
Chlorinated-Dechlorinated											
211-III-12	1.	0	0	0	0	0	0	0	0	0	0
Chlorinated-Dechlorinated											
211-III-12	2.	0	0	0	0	0	0	0	0	0	0
Ozonated											
211-III-13	1.	0	0	0	0	0	0	0	0	0	0
Ozonated											
211-III-13	2.	0	0	0	0	0	0	0	0	0	0
Control	1.	0	0	0	0	0	0	0	0	0	0
Control	2.	0	0	0	0	0	0	0	0	0	0

REMARKS: pH adjusted from about 5.0 with a concentrated (100%) solution of sodium hydroxide to between 6.0 and 7.0 (added to all test samples).

TABLE 1-15

TEST DATE (start):	June 3, 1977	TEST STOCK	No pretest
(sampled):	June 2, 1977	CONDITION:	mortality
BIOASSAY PROCEDURE:	Static 96-hour	DISSOLVED OXYGEN	
TEST SPECIES:	Rainbow Trout	RATE:	7.8 to 10.2 mg/L
DILUTION WATER:	Dechlorinated Acton	pH RANGE:	6.0 to 8.1
	Tap Water	TEMPERATURE:	15 ± 1°C
STOCKING RATIO:	Average 2 Litres/Gram		

Sample	0	$\frac{1}{4}$	$\frac{1}{2}$	1	2	4	8	24	48	72	96
- percent mortality at time (hours) -											
Secondary Effluent											
211-III-14	1.	0	0	0	0	0	0	0	0	0	0
Secondary Effluent											
211-III-14	2.	0	0	0	0	0	0	0	0	0	0
Final Effluent											
211-III-15	1.	0	100	100	100	100	100	100	100	100	100
Final Effluent											
211-III-15	2.	0	100	100	100	100	100	100	100	100	100
Chlorinated											
211-III-16	1.	0	0	0	100	100	100	100	100	100	100
Chlorinated											
211-III-16	2.	0	0	0	100	100	100	100	100	100	100
Chlorinated-Dechlorinated											
211-III-17	1.	0	0	0	0	0	0	0	0	0	0
Chlorinated-Dechlorinated											
211-III-17	2.	0	0	0	0	0	0	0	0	0	0
Ozonated											
211-III-18	1.	0	0	0	0	0	0	0	0	0	0
Ozonated											
211-III-18	2.	0	0	0	0	0	0	0	0	0	0
Control											
	1.	0	0	0	0	0	0	0	0	0	0
Control											
	2.	0	0	0	0	0	0	0	0	0	0

REMARKS: pH adjusted from about 5.0 with a concentrated (100%) solution of sodium hydroxide to between 6.0 and 7.0 (added to all test samples).

TABLE 1-16

TEST DATE (start):	June 7, 1977	TEST STOCK	No pretest								
(sampled):	June 5, 1977	CONDITION:	mortality								
BIOASSAY PROCEDURE:	Static 96-hour	DISSOLVED OXYGEN									
TEST SPECIES:	Rainbow Trout	RATE:	8.7 to 10.3 mg/L								
DILUTION WATER:	Dechlorinated Acton	pH RANGE:	5.7 to 8.7								
	Tap Water	TEMPERATURE:	15 ± 1°C								
STOCKING RATIO:	Average 2 Litres/Gram										
Sample	0	$\frac{1}{4}$	$\frac{1}{2}$	1	2	4	8	24	48	72	96
- percent mortality at time (hours) -											
Secondary Effluent											
211-III-19	1.	0	0	0	0	0	0	0	0	0	0
Secondary Effluent											
211-III-19	2.	0	0	0	0	0	0	0	0	0	0
Chlorinated											
211-III-20	1.	0	0	70	100	100	100	100	100	100	100
Chlorinated											
211-III-20	2.	0	0	100	100	100	100	100	100	100	100
Chlorinated-											
Dechlorinated											
211-III-21	1.	0	0	0	0	0	0	0	0	0	0
Chlorinated-											
Dechlorinated											
211-III-21	2.	0	0	0	0	0	0	0	0	0	0
Ozonated											
211-III-22	1.	0	0	0	0	0	0	0	0	0	0
Ozonated											
211-III-22	2.	0	0	0	0	0	0	0	0	0	0
Control	1.	0	0	0	0	0	0	0	0	0	0
Control	2.	0	0	0	0	0	0	0	0	0	0

REMARKS: pH adjusted from about 5.5 with a concentrated (100%) solution of sodium hydroxide to between 6.0 and 7.0 (added to all test samples).

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- percent mortality at time (hours) -

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TEST DATE (start):	June 24, 1977	TEST STOCK	No pretest
(sampled):	June 20, 1977	CONDITION:	mortality
BIOASSAY PROCEDURE:	Static 96-hour	DISSOLVED OXYGEN	
TEST SPECIES:	Rainbow Trout	RATE:	9.2 to 10.4 mg/L
DILUTION WATER:	Dechlorinated Acton	pH RANGE:	8.3 to 8.6
	Tap Water	TEMPERATURE:	15 ± 1°C
STOCKING RATIO:	Average 2 Litres/Gram		

[illegible]

APPENDIX IIMICROBIOLOGICAL MATERIALSAND METHODS

APPENDIX II - MICROBIOLOGICAL MATERIALS AND METHODS

A. Sampling Procedures

Whenever a bacteriological analysis was desired, two grab samples were collected in sterile 32 oz. glass bottles (Consolidated Bottle Company, Toronto) which contained sodium thiosulphate (BDH Chemicals, Toronto) to give a final concentration of 100 mg/L.

In Phase I of the study, secondary effluent was collected in plasticlined 45 gallon drums on the afternoon of the day prior to a laboratory study. During the laboratory study, grab samples were taken from the drums, and refrigerated at 4°C if they could not be analyzed within three hours. Otherwise, the samples remained at room temperature. All samples were analyzed on the day of the study.

In Phase II and Phase III of the study, the grab samples were received by the laboratory within three hours after collection. Microbiological analyses were begun in the laboratory as soon as the samples were obtained.

B. Microbiological Tests

(i) Fecal coliform counts were determined according to APHA Standard Methods 1 by membrane filter procedures. The 0.45 micron, 47 mm white gridded membrane filters (Millipore Corporation) were incubated on Bacto m-FC agar (Difco Laboratories, Detroit) in a 44.5°C water bath (Blue M Electric Company, Illinois) for 20 ± 2 hr. Colonies were counted with the aid of a low power binocular microscope. A maximum of 50 ml of sample were filtered. Therefore the detection limit of the assay was approximately two counts per 100 ml of sample.

(ii) Standard plate counts were also performed by a membrane filter procedure. The filtration procedure was performed in the same manner as that used for the fecal coliform count except that 0.45 micron, 47 mm diameter black-gridded membrane filters (Millipore Corporation) were used. The filters were placed on Bacto Tryptone Glucose

Extract Agar (Difco Laboratories) and incubated at room temperature (22 - 24°C) for three days. Colonies were counted with the aid of a low-power binocular microscope. A maximum of 1 ml of sample was introduced to the filter unit. Therefore, the detection limit was approximately one count per ml of sample.

- (iii) Adenosine triphosphate (ATP) was determined by the bioluminescent firefly luciferin-luciferase assay [2] with an ATP Photometer (Labline, Illinois). The method used was a Dearborn internal procedure. The results have been expressed in nanograms (ng) of ATP per ml of sample.
- (iv) The presence of salmonella was determined according to the test protocol recommended by Tennant et al [3]. All media were the Bacto brand supplied by Difco (Illinois). The test protocol was as follows:

The bacteria were concentrated by filtering 500 ml of aqueous sample through 0.45 micron 47 mm diameter membrane filters (Millipore Corporation). When samples contained a relatively high amount of suspended solids, either a media pad (Millipore Corporation) or a glass fibre filter (type FG/F, Whatman Incorporated) was stacked onto the membrane filter to reduce the tendency of the membrane filter to plug. Usually no more than five filter changes were required to filter the 500 ml aliquot. All filters and pads were aseptically transferred into beakers (Pyrex) containing 100 ml of tetrathionate enrichment broth which had been pre-warmed to 41.5°C. In a similar fashion, filters from a second 500 ml aliquot were placed into pre-warmed cysteine selenite enrichment broth. When sludge samples were tested, 10 ml of the sludge were added to 300 ml of enrichment broth. Otherwise, procedures were the same.

Beakers containing the filters and enrichment broths were incubated for 48 hours at 41.5°C in a Thelco incubator. Both enrichment broths were then plated on Brilliant Green agar and on XLD

agar plates. These plates were incubated for 24 hrs, at 41.5°C. Two to five colonies suspected of being salmonella were isolated from each selective agar plate on TGE slants on which they were held for further study.

Presence of salmonella was defined as positive for a sample when any of these isolates behaved characteristically in the following test scheme: The isolate was purified by streaking on MacConkey Agar. If the culture was non-lactose fermenting, it was re-isolated to a TGE agar slant. From this culture, cytochrome oxidase, Triple Sugar Iron (TSI) test were performed, and with the Minitex (BBL) disc system, ONPG and phenylalanine deaminase tests were performed. All tests were performed at 37°C.

If the purified culture was salmonella positive according to these tests, it was re-streaked on a TGE slant, incubated for two days at 37°C, and held at 4°C for possible serological tests.

REFERENCES

1. American Publication Association, Standard Methods for the Examination of Water and Wastewater, Fourteenth edition, American Public Health Association, New York (1975).
2. McElroy, W.D., Proc. Natl. Acad. Sci., U.S., 33, 342 (1947).
3. Tennant, A.D., R. Toxopeus, J.A.P. Bastien, M. Beauchamp, and J. Vanderwint. Technology Development Report EPS 4-OR-75-1, Environmental Protection Service, Environment Canada, Ottawa (1975).

APPENDIX III

PROCEDURE FOR 96-HOUR ACUTE

LETHALITY STATIC TEST

APPENDIX III - PROCEDURE FOR 96-HOUR ACUTE LETHALITY STATIC TEST

1. The applicable portions of APHA*, Section 231, can be used as a basic for this test procedure except as modified in this procedure.
2. Rainbow Trout (Salmo gairdneri Richardson) shall be used as the standard test organism for the test procedure.
3. Only healthy, standardized stocks of properly acclimated Rainbow Trout shall be used.
4. Each acute lethality test requires that at least 10 fish be exposed to a representative portion of the composite sample for a period of 96 hours, and that an equal number of fish be exposed for the same period under identical conditions to water used for holding fish stocks (control fish).
5. This test is invalid if greater than 10 percent of the control fish die.
6. For each gram of fish there shall be at least 1.5 litres of fresh test sample per 96-hour test.
7. The minimum water depth in any test vessel shall be ten centimetres (10 cm).
8. The test sample shall be aerated or oxygenated with only that amount of air or oxygen required to maintain a minimum dissolved oxygen level of 9 mg/L. Aeration or oxygenation shall be minimized to reduce the stripping of volatile compounds or the oxidation of acutely lethal components in the test sample.
9. In any test, individual fish shall weigh between 0.5 and 10 grams and the weight of the largest fish shall not be more than twice the smallest.
10. The test shall be conducted at $15^{\circ} \pm 1^{\circ}$ Celsius.
11. The number of dead fish in the treatment and control vessels shall be recorded at $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, 4, 8, 24, 48, 72 and 96 hours.

* Standard Methods for the Examination of Water and Wastewater, 13th Edition, published jointly by the American Public Health Association, American Water Works Association and the Water Pollution Control Federation (1971).

12. There shall be no direct adjustment of the pH or other chemical characteristics of the test sample.
13. When transportation or storage of a composite sample is necessary, special precautions must be used to minimize degradation. The sample shall be kept in sealed containers which are completely filled to the exclusion of all air. If it is necessary for the sample to be stored more than 60 hours between collection and testing, then the sample shall be brought to a temperature range of 10°C to 6°C as soon as possible after collection and maintained at this temperature range until just prior to being tested. Acute lethality testing should commence as soon as possible and within four days of sampling.

